VIEW OF SIDE-CAÑONS OF THE COLORADO.

(From Report of Lieut. Ives to the United States Government.)

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THE

STUDENT'S MANUAL

OF

GEOLOGY

BY

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RE-CAST AND IN GREAT PART RE-WRITTEN

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PREFACE.

The Author of this work had made some progress in the preparation of the present edition before the illness seized him by which he was removed from among us. Finding the task to be greater than, with his impaired health, he could accomplish, he asked me to relieve him of it; and I accordingly undertook to prepare this re-issue. My labours, however, were unfortunately suspended for nearly a year in consequence of a fever caught among the volcanic islands of the Liparis. Hence the delay in the appearance of the work.

The reader will observe, on comparing the present with former editions, that so many changes have been made that it may in some respects be regarded as a new book. A large mass of additional material has been added; but, by adopting a different mode of printing, this has been effected without adding to the bulk of the volume.

The section on Mineralogy (Chapters II. and III.) has been entirely re-written by Dr. Sullivan at Mr. Jukes's request. Chapters IV. and V. were partly revised by Mr. Jukes and partly by myself—my share consisting in adding further information to the descriptions of the different varieties of rocks. As the Author had completed the revision of this portion of the Work without changing the classification formerly adopted, I did not consider myself at liberty to make

any alteration therein. Chapters VI. to XII. were revised by the Author himself. Chapter XIII. has been re-written by me. It contains a new classification and description of the Trap-rocks. Chapters XIV. and XV. were re-cast, chiefly by the Author.

A novel feature in this Edition is the insertion of a new Part on Dynamical Geology (Part II.)—a portion of the science which is not usually treated fully in text-books. In preparing it I have availed myself of all the material existing in the last edition. Nearly the whole of Chapter XVI. is thus derived. From that portion of the book onward the material is chiefly mine, the paragraphs transferred from the previous edition being specially indicated in footnotes. Chapter XIX. is chiefly from that edition. Mr. Jukes left in manuscript some notes on Denudation; these, where they could be used, I have inserted as quotations.

Part III., on Palæontology, re-appears with little alteration.

In the revision of Part IV., no portion of which had been touched by Mr. Jukes, I have been assisted by the valued aid of my colleagues of the Geological Survey. Mr. W. H. Baily, F.G.S., has revised the Palæozoic fossil-lists. The account of the Rhætic beds has been corrected by Mr. H. W. Bristow, F.R.S., who has likewise made some changes and additions in the Oolitic, Cretaceous, and Eocene chapters. The description of the English Coal-measures has been revised by Mr. E. Hull, F.R.S., who has also furnished notes for the improvement of the Permian and Trias chapters. Mr. Whitaker has looked over the Cretaceous and older Tertiary pages. The account of the Jurassic and Cretaceous rocks has been touched up by Mr. Judd. But we have not deemed it desirable to attempt more in this part of the book than to correct what time had shown to be erroneous, and to add references to more recent

researches. The last two chapters, however, I found it necessary to re-write.

Professor Huxley has furnished a new Synopsis of the Animal Kingdom, which appears in the Appendix. The Table of the Vegetable Kingdom was prepared by the late Dr. W. K. Harvey for Mr. Jukes.

In the course of the revision, it was found that the section on the "Life of the Period," appended to the chapters on the various geological formations in former editions, involved so much repetition from the previously given fossil-lists, and required so much labour to re-cast them, that, after some progress had been made with them, it was deemed better to omit them altogether.

Great change has been made in the mode of printing adopted for the present edition. In the first place, illustrative detail has been thrown into smaller type; and, in the Mineralogical and Petrographical portions of the volume, the specific descriptions of minerals and rocks have been similarly printed. At the same time a copious use has been made of bold type for the division of subjects into heads, so that the student may rapidly and easily follow the arrangement adopted.

I regard it as one of the essential features of such a Manual as the present, that it shall give as full and frequent reference as possible to the authorities where the subjects it discusses may be found by the student treated in detail. Accordingly, I have endeavoured to supply this feature; and I trust that the copious footnotes will enable the student to turn at once to the memoirs on any special subject which he may wish to investigate.

I am well aware that there cannot fail to be omissions and inaccuracies in the following pages, and I shall be glad

to receive any corrections which the reader may note. It has been a labour of love to prepare this volume, not alone on account of the ties of friendship which bound me to its lamented Author, but because his work has always appeared to me one of the best Manuals in our language, and one well deserving of every effort to keep it abreast of the onward march of science.

ARCH. GEIKIE.

October 1871.

FROM PREFACE TO LAST EDITION.

By the liberality of the publishers I have been enabled to take advantage of the presence of Mr. W. H. Baily in Dublin, who compiled for me lists of characteristic fossils, which, with some modifications, are those given in the third part of the work. Mr. Baily also drew on the wood the figures which make the fifty "fossil groups" by which that part is illustrated. To the names of the fossils which are not figured in them, I have appended references to figures in other works, choosing, where I could, the most popular books, such as Lyell's and Phillips's Manuals, and the Tabular View of Characteristic British Fossils published by the Christian Knowledge Society; but where no figures exist in such works, I have referred to more recondite sources, such as the publications of the Palæontographical Society, Sowerby's *Mineral Conchology*, Sir R. I. Murchison's *Siluria*, and others. Morris's *Catalogue of British Fossils* has necessarily been my chief guide in selecting these references with respect to all post-Silurian fossils, the catalogue by Morris and Salter in the last edition of *Siluria* taking its place for those of the previous periods.

I am indebted to my colleague, Mr. G. V. Du Noyer, for some sketches, and for the drawing of some of the diagrams, but most of the latter were drawn by myself, which will in great measure account for the roughness of their execution.

This roughness, however, is not altogether undesigned, since I wished to make them just such figures as a lecturer would draw on his black board, and not to lead the student to believe, from any care discernible in the drawings, that they were intended for actual representations of existing objects. A diagram is merely a condensed explanation addressed to the mind through the eye, instead of through the ear. If it is intelligible, and assists the verbal description, it answers its purpose; it is a mistake to endeavour to convert it into a picture, and it is better to avoid anything calculated to mislead the mind into the supposition that it would have been one if the draughtsman could have made it one.

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CHAPTER I.

INTRODUCTORY.

It is not easy to give an accurate and comprehensive definition of the science of Geology; for its nature is so complex and various, that it is difficult in a few words either to specify its object or to assign its limits.

It is, indeed, not so much one science, as the application of all the physical sciences to the examination and description of the structure of the earth, the investigation of the agencies concerned in the production of that structure, and the history of their action.

We might, perhaps, without impropriety, say that all the physical sciences are included under two great heads—namely, Astronomy and Geology; the one comprehending all those sciences which teach us the constitution, the motions, the relative places, and the mutual action of the Astra, or heavenly bodies; while the other singles out for study the one Astrum on which we live—namely, the Earth. Geology would, then, include all the sciences which investigate the nature and the distribution both of the inorganic matter of our globe, and of the living beings that inhabit it. These sciences are—first, that of Chemistry and Mineralogy (which may be called one), which teaches us what are the elements of which terrestrial matter is composed, and what are the laws which govern the combinations of those elements into all the variety of known substances, solid, fluid, or gaseous, and the forms, properties, and qualities of those substances; secondly, the science of Meteorology and Physical Geography (which may also be looked on as one), which describes to us the form and disposition of land, water, and air, and the distribution of the temperatures and motions that affect them; and thirdly, that of Natural History (or Biology, the science of life), including Botany and Zoology in their widest signification. The sciences commonly included under the head of Physics, those which teach us the nature and laws of magnetism, electricity, light, heat, force, and motion, would be common ground to Geology and Astronomy, serving to bind together all human knowledge of matter and its laws into one great whole.

In giving this high place to Geology, I have no desire unduly to exalt it at the expense of the other sciences. My object is to show

that this large view of Geology is not only a true, but a necessary one; and that if we do not sometimes look at it from this aspect, we cannot rightly understand what Geology is.

That it is true, is shown by the very fact of the late appearance of Geology in the world of science. It was not till some very considerable advances had been made in all the physical sciences, that Geology could begin to exist in any worthy form. It was not till the Chemist was able to explain to us the true nature of the mineral substances of which rocks are composed; nor till the Geographer and the Meteorologist had explored the surface of the earth, and taught us the extent and the form of land and water, and the powers of winds, currents, rains, glaciers, earthquakes, and volcanoes; nor till the Biologist had named, described, and classified the greater part of existing animals and plants, and explained to us the laws of their distribution;—that the Geologist could, with any chance of arriving at sure and definite results, commence his researches into the structure and composition of rocks, and the causes that produced them, or utilise his discoveries of the remains of animals and plants that are enclosed in them. He could not till then discriminate with certainty between igneous and aqueous rocks, or between the remains of living and of extinct animals, and was therefore unable to lay down any one of the foundations on which his own science was to rest.

Neither would it be satisfactory if we were to limit the science of Geology to any special period of the earth's history; to assign to it, for instance, all time previous to the existence of the human race, and, uniting all the natural sciences under it up to that point, to consider it to be brought to an end, or to split up and diverge into the many independent sciences that concern our contemporary existences. For not only is there no trace of any hard geological boundary line between the human and the pre-human period of the earth's natural history; but there appears in each one of the separate natural sciences a perfect continuity from the remotest geological era to the present time. The present is but a part of the past. The inorganic objects we see around us are the result of processes going on in past time, such as are still at work producing the same results; the living beings around us are either the direct descendants of those that lived formerly, or their substitutes and representatives, the living and the extinct forming parts of one great connected series and chain of species, genera, and orders, each of which parts would be incomplete without the other. There is, therefore, no possibility of making any such division in Geology, or assigning any limit to its range from the earliest period of the earth's ascertainable history to the present moment.

Moreover, as there is no natural science to which the geologist has not to appeal for information upon some point or other in his researches,

so there is none which can be fully and completely studied without the help of the geologist, or without including facts or theories which are commonly and rightly reckoned parts of his peculiar intellectual domain. If he has to call upon the professors of each one of the physical sciences in turn, for assistance in his own investigations, he is sure, sooner or later, to repay the obligation, by the discovery of a number of facts that enlarge the boundaries of the science he has applied to, or by the statement of many problems, the solution of which throws light upon parts of it that have been hitherto imperfect and obscure.

The reader must not infer from what has been said, that in order to be a geologist, he must be thoroughly acquainted with the whole circle of the physical and natural sciences. Such universal acquirement few men have the power to attain to, and of these still fewer retain the ability and the will to make original advances in any particular branch.

No man, however, can be a thorough geologist without being acquainted, to some extent, with the general results of other sciences, and being able both to understand them when stated in plain untechnical language, and to appreciate their application to his own researches. Such a general acquaintance involves neither profound study, nor requires any great power of mind above the average of human intellect. It is, indeed, what every well-educated man ought to possess.

It may be said with perfect truth, that the geologist is less able than any other student of science to pursue his investigations alone, and independently of the assistance of others; but this is, in fact, only saying in other words that which I am insisting on—namely, that Geology in its highest and widest sense embraces all the physical and natural sciences, and is, as it were, made up of them. If, however, this wide scope be properly given to the term Geology, and it be made to include every physical science that treats of anything belonging to the earth, what, it may be asked, is the special business to which the geologist devotes himself as distinct from the follower of other sciences? What is that which he does, and the others do not? Above all, what is that which he teaches to the rest in return for the knowledge communicated to him?

The answer to these questions will show us that there is another and a more restricted sense of the word Geology than the wide one in which we have been using it. This sense is rather the one formerly attached to the word Geognosy, by which we may understand the knowledge of the nature and position of the different masses of mineral matter of which different districts are composed, without reference to the history of their production. This was the early meaning of the word Geology, or Geognosy—namely, the examination and description of the different varieties of rocks and the minerals they contained. Geology was looked upon as a geographical mineralogy. No one,

indeed, could have anticipated, from the mere study of masses of rock, where, to a partial view, all seems confusion and irregularity, the wonderful order and harmony which arise from more extended observation, and the almost romantic history which becomes at length unfolded to our perusal. To discover the records on which this history is founded, and to understand their meaning aright, long-continued and wide-spread observation in the field, and patient comparison of the observed facts in the closet, are absolutely necessary.

The collection and co-ordination of these facts is the proper and peculiar business of the Geognost. The ditch, the "cutting," the quarry, and the mine, the cliff, the gully, the mountain-side, and the river-bank, are his "*subjects*," which he has to examine and dissect. He must describe the minutiæ of the structures they expose, and arrange the facts they may afford, depicting their lineaments on maps and sections, and recording them in written descriptions. The business of the Geognost, then, is to make out, from indications observed at the surface and in natural and artificial excavations, the internal structure, the *solid geometry*, of district after district, and country after country, until the whole earth has been explored and described. If, while so doing, he notes all those facts which may enable him or others to explain how that structure has been produced, he then becomes a Geologist.

It might at first be thought that, in order to make out the solid structure of the land, it would only be necessary to understand the nature of the mineral matters of which it is composed, and that for this purpose no knowledge of organic or living beings would be required. It is, however, one of the most remarkable results of geological science, that an acquaintance with organic, and especially with animal forms, is at least as necessary for a geologist as a knowledge of minerals, and that a correct knowledge of organic remains (that is, portions of fossil plants and animals) is in some cases a more certain guide in unravelling the structure of complicated districts than the widest acquaintance with inorganic substances.

The cause of this necessity, puzzling enough perhaps at first, may be briefly stated as follows. When we examine the structure of the crust of the globe, we find that its several parts have been produced in succession, that it consists of a regular series of sedimentary deposits (all called by geologists *rocks*), formed one after another during successive periods of great but unknown duration. Now, the mineral substances produced during any one of this vast succession of ages do not appear to have had any essential difference from those formed under like circumstances at another. We cannot, therefore, with any certainty discover the order of time in which the series of rocks was formed, or the order of superposition which they consequently preserve, from an

examination of their mineral character or contents only. The animals and plants, however, living at one period of the earth's history were different from those living now, and different from those living at other periods. There has been a continuous succession of different races of living beings on the earth, following each other in a certain regular order, and, when that order has been ascertained, it is obvious that we can at once assign to its proper period of production, and therefore to its proper place in the series of rocks, any portion of rock we may meet with containing any one, or even any recognisable fragment of one, of these once living beings. Just as when we find under the foundation-stone of any ancient building a parcel of coins of any particular sovereign, we know that the erection of that building took place during his reign, so when we find a fragment of a known "fossil" in any piece of rock, we feel sure that that rock must have been formed during the period when the animal or plant of which that fossil is a part was living on the globe, and could not have been formed either before that species came into existence, or after it became extinct.* In cases, therefore, where the original order of the rocks has been confused by the action of disturbing forces, or where the rocks themselves are only exposed to view at wide intervals, their periods of deposition and consequent succession in superposition may be more easily and certainly ascertained by the determination of their fossil contents than by any other method. Practically, it has been found that while a very slight acquaintance with the most ordinary forms of some ten or a dozen of the most frequently occurring minerals is all that a geologist must *inevitably* learn of mineralogy, the number of fossil animals and plants, with the forms and the names of which he will have to make himself familiar, will often have to be reckoned by hundreds. This branch of geological knowledge is now known under the name of Palæontology.

Perhaps, however, the tendency of late years has been to neglect to too great an extent the bearing of mineralogical knowledge on Geology. There are many subjects on which we have still to ask the chemist and mineralogist to enlighten us. One deficiency which is particularly obvious in Britain is the want of a good nomenclature of rocks, and especially of what are known as igneous rocks. Since the publications of Jameson and Maculloch, few attempts have been made in English to supply this deficiency, and to bring up our lithological nomenclature to the present state of chemical and mineralogical knowledge. Many works have in the meanwhile appeared in Germany and in France, which have treated the subject of rocks more or less satisfactorily. This branch of Geology, however, is still in a very unsatisfactory state.

* The very rare and exceptional cases in which ancient coins *may* have been deposited in the foundation of a recent building, or fossils originally in one rock may have been washed out of it and buried in another, need not more than a passing notice.

In order to reduce the great subject of Geology to something like order, it appears advisable to divide it into four heads, for which we may use the terms—1, Geognosy; 2, Geological Agencies; 3, Palæontology; and 4, Stratigraphy, or the History of the Formation of the Series of Stratified Rocks. This will enable us to describe separately those general facts which either are, or may be, common to the rocks of all ages, and those general laws which regulated the distribution of life in all epochs of the world's history, and leave us free to give a condensed statement of the fourth part without stopping to describe special instances of general facts.

By Geognosy I would understand, then, the study of rocks independently of their arrangement into a chronological series, and I would divide it into two parts—Lithology and Petrology.* By Lithology † I would mean the study of the mineralogical composition, the structure, the texture, and other characters of rocks, such as could be determined in the closet by the aid of hand specimens. By Petrology I would designate the study of rock-masses, their planes of division, their forms, their positions and mutual relations, and other characters that can only be studied in "the field," but without entering on the question of the geological time of their production.

In the second division fall to be described all those forces by which rocks have been and are now formed, and by which the surface of the earth is modified.

Under the head of Palæontology I wish to give the heads of several great questions as to the laws which have governed the distribution of life both in space and in time, as also to indicate some of the chief points in the structure of the more important extinct races, and their relations to those now living. I shall also endeavour to point out the practical bearings of this subject, both scientific and economical.

Having thus described, under separate heads, facts and generalisations common to the whole subject, as well as structures and phenomena which may recur during every geological period, I shall, under the head of "History of the Formation of the Crust of the Globe," give a condensed abstract of that history, in the form of a chronological classification, mentioning some of the principal and typical groups of rocks known to have been produced, and a few of the more common and best marked fossils which lived on different parts of the earth during each of the known great periods of its existence.

* I am, of course, aware that these words have no great difference of meaning, but after in vain endeavouring to think of, or to coin, a word that should express what I have here designated Petrology, and not feeling satisfied with words like Naumann's "Geotektonik," I think it would be simpler if geologists were to agree to take "lithos" to signify "a stone" that could be handled, and "petros" as a mass of rock, than for us to invent a new term.

† This term is thus synonymous with *Petrography*, which is the word in use in Germany.

I. GEOGNOSY.

SECTION I.

LITHOLOGY.

CHAPTER II.

COMPOSITION AND FORM OF MINERALS.

LITHOLOGY, or the study of the mineral structure of rocks, is based on Mineralogy. For the proper understanding of Mineralogy, some knowledge of chemistry is essential. This must be gained, not only from the study of books, but from practice in the laboratory.

In order to understand Lithology, however, an acquaintance with the whole science of Mineralogy, though always useful, is by no means necessary, since the minerals which are the essential constituents of rocks are very few compared with the whole number of minerals. There are two methods of studying Mineralogy—one giving principal attention to the chemical composition of minerals, the other laying most stress on their external and internal characters and physical properties.

The full details of the science of mineralogy must be sought in the works specially devoted to that subject. But for the guidance of the geological student, a general outline of the laws of mineralogy, in so far as the science bears upon his studies, is given in the following pages. This outline has been prepared by Dr. W. K. Sullivan, and is divided into three parts—1. The Laws of Composition, under which the chemical aspects of mineralogy are considered; 2. The Laws of Form, under which the external and internal characters and physical properties of minerals are treated; and 3. The Composition and Properties of Rock-forming minerals.

The meaning commonly given to the word "mineral" is vague. It is therefore necessary to define it when used as a scientific term.

A mineral is an inorganic body, having theoretically a definite chemical composition, and usually a regular geometric form.

The chemical composition and the geometric form are both produced and modified under the influence of general laws.

1. Laws of Composition.

Simple and Compound Bodies.—Bodies which can be decomposed, or resolved into two or more bodies having different properties, are called compound bodies; those which cannot be so decomposed, or resolved, are called simple or elementary bodies.

Sixty-three simple bodies are known at present to enter into the composition of the earth. Many of them have been shown to exist in the sun, and with great probability in the stars and nebulæ. It is probable that the heavenly bodies contain many other simple bodies not yet found in the earth, or which do not exist in it.

Combination is not a mere mingling of two or more bodies producing a mixture whose properties partake of those of its constituents, but a union yielding a new body more or less different from either of its constituents, and the formation of which is always attended with the production of heat, and light or electricity.

Chemical Affinity.—The special kind of power or force which is manifested in chemical changes, and which is considered to bring the constituents of a compound together, is designated chemical affinity. When two substances unite together with great energy, and give off great heat, or heat and light, they are said to have great affinity for each other. Bodies which differ very much from each other in their chemical properties have the greatest affinity; those which resemble each other may combine, but the force which binds them together is small, and the compound when formed is not stable.

A great many of the simple bodies possess certain properties in common, such as the power of conducting heat and electricity, and that kind of lustre which we find in a marked degree in gold, silver, copper, and other common metals. Hence these bodies are called metals or metallic bodies. Those which have not those properties are called non-metallic bodies. The metals form very feeble compounds with each

* For detailed information on general mineralogy the student may refer to the Manuals of Dana, Brooke and Miller, Nicol, Phillips, Naumann, etc. Bristow's *Glossary of Mineralogy* is a useful little book. For British minerals the Manual of Greg and Lettsom should be consulted. Chemical mineralogy is treated of in Gmelin's *Handbook*, translated by the Cavendish Society; see also Bischoff's *Chemical Geology*. Blowpipe analysis is best described in Plattner's *Probirkunst mit dem Löthrohre*, 4th edit. 1865; and in F. von Kobell's *Tafeln*, 8th edit. 1864. Much useful information regarding the minerals which form essential or important ingredients in rocks will be found in Zirkel's *Lehrbuch der Petrographie*, 1866; Senft's *Classification der Felsarten*, 1857, also his *Krystallinischen Felsgemengtheile*, 1868; Naumann's *Lehrbuch der Geognosie*, vol. i.; Cotta's *Gesteinslehre*, translated into English by P. H. Laurence, 1866.

other, so feeble that they are almost like mixtures. Such compounds are termed alloys. When one of the metals is mercury, they are called amalgams. The non-metallic bodies combine with great energy, both with the metals and with one another. The compounds formed by the non-metallic bodies with one another give rise to the class of substances we term acids; the union of some non-metallic bodies with metals gives rise to a class of compounds called bases. Among the non-metallic bodies chlorine exhibits the greatest amount of active energy, hence the non-metallic bodies are sometimes called chlorous bodies, and the metals basylous.

Atoms.—The smallest indivisible quantity of a simple body which can act in a chemical change is called an atom (ἄτομος). The atomic theory supposes that there is a limit to the possible division of matter —that is, that the matter of the universe is constituted of exceedingly small particles, impenetrable and indivisible, of the same size but of different weights. The term may be, and now indeed is, used generally, without any reference to the atomic theory, and in a mere abstract sense.

Molecules.—The smallest particle of a simple body that can exist isolated, or in a free state, is called its molecule. The molecules of the simple bodies are generally formed of two atoms; a few contain four atoms, or more. In some cases the molecule appears to be indivisible, so that we may consider the atom and molecule to be identical. An element may have two or even more distinct molecules, *e.g.* oxygen and sulphur. In such cases the properties of the body change when the molecules are different. The term allotropism is given to this phenomenon, and will be specially noticed in connection with the laws of form. The molecule of a compound is the smallest particle which can exist isolated, without decomposition into its constituents.

Radicles.—Two or more atoms combined together are capable of performing the functions of simple bodies. Such groups of atoms are called compound radicles—the term simple radicle being applied to simple bodies. Compound radicles may be best described as groups of atoms which remain together through a series of chemical transformations. We may assume a compound radicle to exist in a series of bodies, although the radicle may be incapable of forming a free molecule—that is, of existing in an isolated state. The word atom is also applied to radicles. Radicle comes from *radicula*, a diminutive of *radix;* the name therefore implies that it is the nucleus or root of a series of compounds.

Definition of Chemistry.—All changes which affect only the motions, distances, or positions of the molecules of a body towards each other, may be described as physical, such as the expansion and fusion of

bodies by heat, the magnetising of iron, etc. All changes which affect the atomic constitutions of bodies are chemical.

Chemical Changes.—The chemical changes which take place in bodies may be conveniently classed in three categories:—

I. Those affecting the molecules of simple bodies, or allotropic changes.

1. Re-arrangement of the atoms of two or more molecules of simple bodies into more condensed molecules, such as the union of three two-atomed molecules of sulphur to form one six-atomed molecule.

2. The converse of the preceding, or the resolution of condensed molecules into simpler ones.

3. A molecule may also be altered, without any change in the number of atoms, by a mere modification of position of the atoms within the molecule.

II. Changes produced by heat, etc., on the molecules of compound bodies.

1. The re-arrangement of the atoms of a compound body so as to change the nature of the compound radicles, as in the conversion of cyanate of ammonium into urea; or merely to produce more condensed molecules, such as the action of heat upon chromic oxide, etc.

2. The union of two or more molecules of a body to produce a more condensed or complex molecule, with the separation of one or more simpler molecules, such as the union of two or more molecules of silicic acid to form a condensed acid, and the separation of molecules of water.

3. By the resolution of the molecules of a compound body into new molecules of different kinds, such as the conversion of wood into coal, gas, petroleum, etc.

III. Action of different kinds of molecules upon each other, or ordinary chemical changes.

1. The direct union of two or more different molecules, such as the combination of water with minerals to form hydrated minerals.

2. The replacement in a compound molecule of one or more simple or compound atoms by one or more simple or compound atoms of a different kind, or what is called double decomposition, such as the action of acids upon bases, or of salts upon one another. The greatest number of chemical changes occurring in minerals belong to this category.

Proportional Numbers or Atomic Weights.—The smallest relative proportion by weight of a simple body, compared with a unit weight of hydrogen, which can take part in any chemical reaction, is called its proportional number; and as the smallest abstract particles which are supposed to act in chemical changes are called atoms, these numbers, or, in some cases, simple multiples of them, are properly designated

atomic weights, or the relative weights of the atoms, compared with that of the atom of hydrogen taken as unity. These numbers also represent, with few exceptions: 1. The relative weights of equal volumes of the gas or vapour, of such of them as either naturally exist as gases, or may be converted into gases, compared, at equal temperatures and under equal pressures, with a unit weight of hydrogen under like conditions. 2. And quantities of those simple bodies that occur in the solid state, which contain as much heat as seven parts of the metal lithium. As seven is the atomic weight of lithium, it follows that the atoms of all the simple bodies that occur in the solid state have the same specific heat.

The atomic weight of the atom of a compound radicle is equal to the sum of the weights of its constituent atoms.

Molecular Weight.—The relative weight of any molecule, compared to that of hydrogen, is called its molecular weight, and is always equal to the sum of the atomic weights of its constituent atoms. With very few exceptions, if indeed there be any real ones, the volumes of all molecules in the state of gas, at the same temperature and under equal pressures, are equal.

Quantivalence of Simple Bodies.—The atomic weights do not always represent the relative quantities which perform the same work or function ; that is, the atoms of the elementary bodies have not equal value in a chemical reaction; that is, they are not equivalent to each other. Thus an atom of sodium is equivalent to one of hydrogen, but one of calcium has twice the value of either. It is found, however, that if the atom of hydrogen be taken as the standard of equivalent value, that of each of the other simple bodies is either equal to that of hydrogen, or a simple multiple of it—as twice, three times, etc. To express this difference in equivalency, hydrogen, and the bodies which are equal to it in equivalency, are termed monads; those whose atoms possess the value of two, three, etc., of hydrogen, diads, triads, tetrads, pentads, hexads. If in a chemical reaction a diad body takes the place of a monad, one diad atom displaces two monad atoms ; in the same way two triad atoms take the place of three diad atoms, of six monad atoms, or of one hexad atom. The term atomicity is sometimes employed to express this quality of atoms, and monads are called monatomic bodies ; diads, diatomic, etc. ; the word polyatomic being used as a general term for all whose atomicity is greater than one. The words monatomic, diatomic, etc., are, however, also used to express the number of atoms in a molecule ; thus the molecule of mercury is said to be monatomic, of hydrogen diatomic, of ozone or allotropic oxygen triatomic, and so on. As this double use of the same word leads to confusion, it is desirable to confine the word atomic to the second and more correct use of it. The word equivalency is however also open to objection, because bodies can

only be said to be equivalent when they are of equal value. To obviate this objection, it has been proposed to coin the word quantivalence for the general quality, and express the special powers of monads by monivalence, of diads by divalence, etc. An atom of a monad is therefore said to be monivalent; that of a diad, divalent, etc. This nomenclature, if generally adopted, would be satisfactory. The atoms of compound radicles are also spoken of as monads, diads, etc.

Notation, Symbols, Formulæ, Equations.—Instead of writing out the names of simple bodies in full, it is very convenient to represent them by symbols. These symbols are the initial letters of their Latin names. When two or more bodies have the same initial letter in their names, the more important body has the initial letter only as symbol, the others take the second letter in addition to the initial letter. If among the simple bodies having the same initial letter there be a non-metallic body, it gets the distinction of the single letter. If there be more than one non-metallic body, or if they are all metals, then the body longest known, or which is most abundant in nature, gets the single letter for symbol. Thus oxygen and osmium are the only substances having O as the initial letter of their name. The symbol of the non-metallic oxygen is therefore O, and that of osmium Os. Again, S is the initial letter of sulphur, selenium, silicon, three non-metallic elements; and of strontium, tin (stannum), and antimony (stibium), three metals. Sulphur is accordingly represented by S; all the others by a second letter. In the names of tin and antimony the two first letters are the same, and as tin is the longest known its symbol is St, while antimony takes Sb.

Symbols always denote atoms, and consequently definite proportions by weight of the bodies they represent. Thus O represents 16 parts of oxygen, and Si 28 parts of silicon.

Compound bodies are represented by putting the symbols of the constituent atoms in juxtaposition. Such groups of symbols are called formulæ. Thus common salt is represented by the formula NaCl. A symbol always represents an atom, a formula a molecule, except in the case of compound radicles. There is now, however, a tendency to represent the more important compound radicles by special symbols, and allow of the rule being made general that formulæ represent molecules. The molecules of compounds frequently contain more than one atom of one or more of the constituent elements; this is expressed by putting a coefficient indicating the number of atoms after the symbol or symbols. Thus fluor-spar, pyrites, magnetite, and calcite, are represented by the following formulæ: CaF_2, FeS_2, Fe_3O_4, $CaCO_3$.

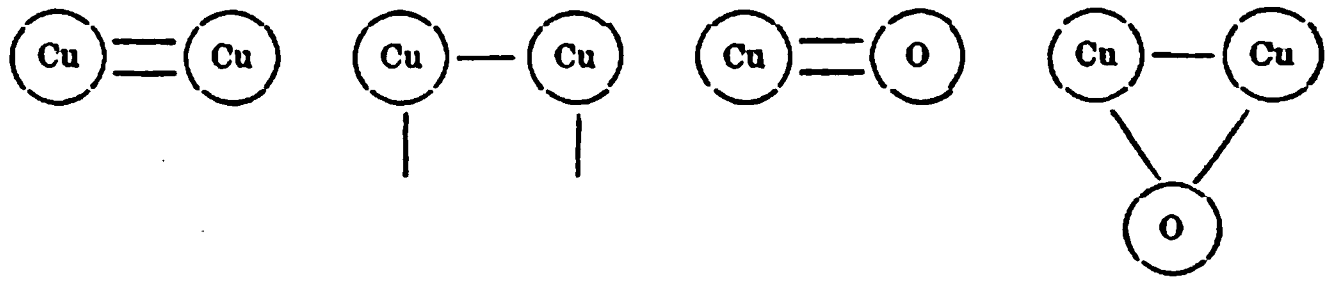
As the quantivalence of atoms governs all their reactions, and the character of the compounds which they form, it is very useful to indicate its value in the case of the different kinds of atoms. This is done by putting accents above, to the right hand of the symbol; thus, Na',

Ca″, Bo‴, Si⁗, indicate that sodium is a monad, calcium a diad, boron a triad, and silicon a tetrad body. In order to avoid the difficulty which the eye would experience in determining a great number of accents, the quantivalence of tetrad and higher bodies is usually indicated by Roman numerals, thus: Si^{iv}, P^{v}.

Trivalent and higher atoms need not necessarily act with their full quantivalence. Thus a trivalent atom can act as a monad, a pentivalent atom may act as a trivalent and as a monivalent atom. A hexad atom may act as a tetrad and as a diad atom. The rule being that perissads, or bodies whose quantivalence is odd, always act as perissads; and artiads, or bodies whose quantivalence is even, as artiads. That is, when an atom exhibits several degrees of quantivalence, these degrees differ by two or four. Thus gold is trivalent as $Au'''Cl_3$, or auric terchloride or terchloride of gold, but it is monivalent in AuCl, in aurous chloride or protochloride of gold. Dr. Frankland uses the word bond to express the power of combination of an atom. A monad has one bond, a diad two, and so on, an atom having as many bonds as degrees of quantivalence. In compound bodies the atoms are held together by the mutual action of these bonds. A pair or two pairs of bonds in an atom may mutually neutralise each other; they are then said to be latent, the bonds that act in combinations are said to be active. Thus a hexad atom of iron may have two pairs of its bonds latent and two active. In this case it acts as a diad. According to this view, in the aurous chloride, Au′Cl above mentioned, two of the bonds of the gold mutually satisfy each other. When all the bonds of an atom are actively engaged with other atoms, it is said to be saturated, and can form no higher compound. When only some of the bonds are active, the atom is not saturated, and is capable of entering into further combinations. In the atoms of every molecule all the bonds are satisfied either by different atoms or by mutual neutralisation. The stability of a molecule depends upon the conditions under which the equilibrium of its atoms is attained.

Two atoms of a polivalent body may combine with each other to form a compound atom, which acts exactly like a simple atom in combinations. Copper, although included among hexad bodies in the list of simple bodies at p. 18, in order not to separate it from the bodies with which it is most related, acts as a diad body in the most important series of compounds which it forms. But it also forms another series of quasi-monad compounds, in which two atoms of copper are assumed to be united together by two bonds, leaving the remaining two to combine with other atoms. In this way we get two oxides of copper, Cu″O, cupric oxide, and Cu_2O, cuprous oxide or sub-oxide of copper. To distinguish the metal in the two states, the term Cuprum is given to the metal in the cupric compounds, and Cuprosum to the metal in the

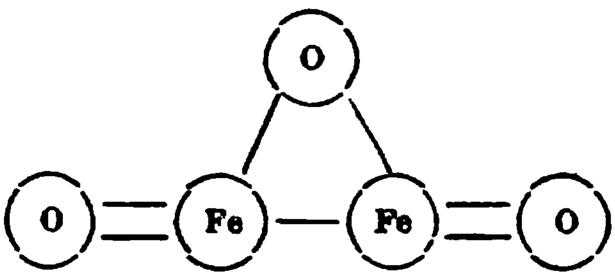
cuprous compounds. The following graphic formulæ will render the constitution of this class of bodies more intelligible:—



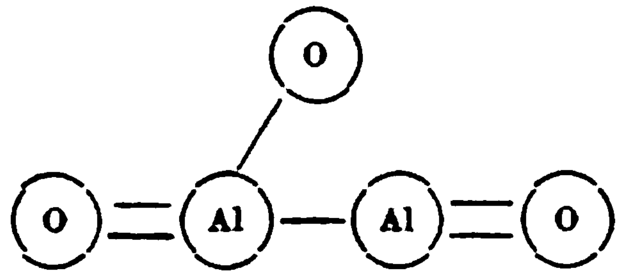
Molecule of Cuprum. | Double atom of Copper, or Cuprosum. | Molecule of Cupric Oxide, or Melaconite. | Molecule of Cuprous Oxide, or Red Copper.

Those who consider aluminium to be a tetrad assume that there is a similar hexadic double atom in all aluminic compounds, so that each atom acts as a quasi-triad atom. In the ferric salts of iron we also assume the existence of a similar double atom. As the compounds of aluminium and iron are of the greatest importance in Geology, it is desirable to explain the usually assumed constitution of the aluminic and ferric compounds. Iron is included among the hexads on account of one or two unimportant compounds. Its principal compounds belong to two series, one in which the metal is a diad: to this series belong the green salts of iron, such as ferrous silicates, which give, with few exceptions, the various shades of green and black to mineral silicates. To the other belong the red salts of iron, such as the silicates which colour rocks red. In these red salts the iron is supposed to consist of two tetrad atoms rivetted together so as to form a double hexad atom, each single atom acting as a quasi-triad atom. As in the case of the two series of copper compounds, the metal in the green salts is sometimes called Ferrosum, and that in the red salts, Ferricum. Some chemists look upon aluminium as a triad metal, an opinion which is supported by the composition of certain artificial aluminic compounds. If aluminium be a triad, it is difficult to see why nearly all its compounds should be so like ferric and chromic compounds, which are certainly not triads. Some again look upon aluminium as a hexad, with an atomic weight of 55, or double that given in the table. This is not the place to discuss the relative merits of these different views, because, whether aluminium be a triad, a tetrad, or a hexad, the least indivisible quantity of that metal which appears to exist in mineral molecules, appears to be 55, which may be represented as Al_2''', made up of two triad atoms, or of two tetrad atoms rivetted together, with the loss of one-fourth of their quantivalence, or as a single indivisible hexad atom, represented by the symbol Al^{vi}. The analogy between aluminic and chromic and ferric compounds, speaks very strongly in favour of the tetrad character of aluminium. The following graphic formulæ, taken from Dr. Frankland's

Lecture Notes, will help to make the tetrad character of the double atoms more intelligible :—



Molecule of Ferric Oxide, or Red Hæmatite.



Molecule of Aluminic Oxide or Alumina, forming the mineral Corundum.

The graphic formula, representing Fe_2O_3, shows how two molecules of ferrous oxide, FeO could become rivetted together by an atom of oxygen into a molecule of ferric oxide.

Some chemists make considerable use of graphic formulæ. They are very useful when cautiously used, but there is always great danger of producing erroneous ideas on the mind when they are used too frequently, or otherwise than as mere explanatory illustrations.

One of the chief uses of symbols and formulæ is to express shortly and clearly the various chemical changes which take place by the action of heat and other forces upon molecules, or of molecules upon each other. The arrangement of formulæ, to express a chemical change, is called an equation. On one side are the formulæ which represent the molecules before the change ; and on the other those of the molecules after the change. Thus, when calcic carbonate, or carbonate of lime, is heated in a limekiln, the change may be represented by the following equation :—

$$Ca''CO_3 = Ca''O + CO_2.$$

Or, when ferrous carbonate or spathic iron is converted, under the influence of air and water, into brown hæmatite, we may express the change thus :—

$4FeCO_3$	+	O_2	+	$3H_2O$	=	$Fe_4{}'''H_6O_9$	+	$4CO_2$.
Spathic iron, or Chalybite.		Oxygen.		Water.		Brown Hæmatite.		Carbanhydride, or Carbonic Acid.

In the first example, only one molecule undergoes change ; in the second, four molecules of chalybite or natural ferrous carbonate, one of oxygen, and three of water, take part in the reaction. The number of molecules of a body engaged in a reaction is indicated, as in the second example, by a large figure placed before the formula of the body. The coefficients always represent atoms, the large figures molecules. Every chemical change should, if practicable, be expressed by an equation, for

it is then only that we can have an accurate notion of the changes which take place in the reaction.

Every formula expresses: 1. The nature of the atoms forming the molecule; 2. The relative proportion of the constituent bodies or radicles; but to fully deserve the name of a formula, it should also express the actual number of atoms in the molecule, or, to speak more correctly, the relative number compared to the molecule of water or of hydrogen. It is, indeed, only when we know this, that a formula can be said to really represent a molecule of a body. The molecular formulæ of a great many volatile bodies of definite composition have been determined. As all molecules in the gaseous state occupy the same space, and as a molecule of hydrogen is assumed to occupy two volumes, we have only to determine the weight of two volumes of the vapour of the body whose formula we seek, as compared to two of hydrogen under the same circumstances as to temperature and pressure, in order to get the molecular weight, that is the sum of the weights of all the atoms in the molecule. When a body is not volatile, we can only determine the formula—that is, the molecule—by analogy with other bodies of analogous composition which are volatile. The formulæ of many minerals, especially of the Silicates, express only the ratio of the number of different kinds of atoms to each other, but give us often no clue as to the constitution of the molecule. Thus the mineral Hornblende is often represented by the extremely simple formula $M''O.SiO_2$, in which M represents an atom of a diad metal; but as hornblende always contains at least two diad metals, calcium and magnesium, the simplest formula it could possibly have would be $CaO.MgO.2SiO_2$, that is, the double of the first. But even this formula could only be true if the ratio of the two metals in the mineral was the same as that of their respective atomic weights; or, in other words, if an atom of each were present. This is, however, never the case; and, besides, most hornblendes contain diad iron, so that the ratio of the metals could only be satisfied by a very large number of atoms of each. Thus, in a crystalline specimen analysed, the simplest formula which could express the ratio of calcium, magnesium and iron, and other substances, was found to be $47MgO.SiO_2$, $20CaO.SiO_2$, $3FeO.SiO_2$, or in all seventy metallic atoms. The usual way to describe such a mineral is to assume the simplest formula, as for example, $M''O.SiO_2$, and say M'' represents variable proportions of calcium, magnesium, iron, etc.; but as M'' represents an indivisible atom, and as the least quantity of any body which could replace another is an atom, it is quite clear that the true formula is a multiple of the simple one. The following table contains the names of all the terrestrial simple bodies now known, classified according to their quantivalence or atomicity, with their atomic weights and symbols:—

Table I.—List of Elementary Bodies.

The Elements whose names are printed in black type, are those which form the minerals of which rocks are chiefly made up. The Elements not separated by a line form a group of closely-related bodies. A line between two bodies shows that their relationship is more remote.

Monads.

Non-Metallic Bodies—

Group	Element	Atomic Weights.	Mean	Symbols.
	1. **Hydrogen**	1		H
	—			
Halogen Elements.	2. Fluorine	19		F
Halogen Elements.	—			
Halogen Elements.	3. **Chlorine**	35·5	mean 80·8	Cl
Halogen Elements.	4. Bromine	80		Br
Halogen Elements.	5. Iodine	127		I

Metals—

Group	Element	Atomic Weights.	Mean	Symbols.
Sodium Elements.	6. Lithium	7		Li
Sodium Elements.	7. **Sodium**	23		Na
Sodium Elements.	—			
Sodium Elements.	8. Silver	108		Ag
Sodium Elements.	—			
Sodium Elements.	9. **Potassium**	39·1	mean 85·8	K
Sodium Elements.	10. Rubidium	85·4		Rb
Sodium Elements.	11. Cæsium	133		Cæ

Diads.

Non-Metallic Bodies—

Group	Element	Atomic Weights.	Mean	Symbols.
Oxygen Elements.	12. **Oxygen**	16		O
Oxygen Elements.	—			
Oxygen Elements.	13. **Sulphur** *	32	mean 79·8	S
Oxygen Elements.	14. Selenium	79·4		Se
Oxygen Elements.	15. Tellurium	128		Te

Metals—

Group	Element	Atomic Weights.	Mean	Symbols.
Magnesium Elements.	16. **Calcium**	40	mean 88·2	Ca
Magnesium Elements.	17. Strontium	† 87·6		Sr
Magnesium Elements.	18. Barium	137		Ba
Magnesium Elements.	—			
Magnesium Elements.	19. Beryllium or Glucinum	9·3		Be or G
Magnesium Elements.	—			
Magnesium Elements.	20. **Magnesium**	24	mean 67	Mg
Magnesium Elements.	21. Zinc	65·2		Zin
Magnesium Elements.	22. Cadmium	112		Cd
Magnesium Elements.	—			
Magnesium Elements.	23. Mercury	200		Hg
	—			

Diads.

Metals—

Element	Atomic Weights.	Symbols.
24. Yttrium	61·7	Y
25. Erbium	112·6	Eb
—		
26. Cerium	92	Ce
27. Lanthanum	93·6	La
28. Didymium	95	Di
—		
29. Thorium	231·4	Th
—		
30. Indium	72	In

Triads.

Non-Metallic Body—

Element	Atomic Weights.	Symbols.
31. Boron	11	B

Metals—

Element	Atomic Weights.	Symbols.
32. Gold	197	Au
—		
33. Thallium	204	T

Tetrads.

Non-Metallic Bodies—

Group	Element	Atomic Weights.	Symbols.	
	34. **Carbon**	12	C	
Silicon Elements.	35. **Silicon**	28	Si	
Silicon Elements.	36. Titanium	50	Ti	Metals.
Silicon Elements.	37. Zirconium	89·6	Zr	Metals.
Silicon Elements.	38. Tin	118	St	Metals.
	—			Metals.
	39. **Aluminium**	27·4	Al	Metals.
	—			Metals.
	40. Lead	207		Metals.
	—			Metals.
Platinum Elements.	41. Rhodium	104·4	Ro	Metals.
Platinum Elements.	42. Ruthenium	104·4	Ru	Metals.
Platinum Elements.	43. Palladium	106·6	Pd	Metals.
Platinum Elements.	—			Metals.
Platinum Elements.	44. Platinum	197·4	Pt	Metals.
Platinum Elements.	45. Iridium	196	Ir	Metals.
Platinum Elements.	46. Osmium	192·2	Os	Metals.

* S, Se, and Te, are hexads, but are placed here because of their close relationship with oxygen in their diad compounds.

† Lead, by its most characteristic compounds, in which the metal acts as a diad, is closely related to this group.

Pentads.

Group	Element	Atomic Weights.		Symbols.
Nitrogen Elements.	*Non-Metallic Bodies—*			
	47. Nitrogen	14		N
	48. Phosphorus	31	mean 76	P
Arsenic Elements.	*Metals—*			
	49. Arsenic	75		As
	50. Antimony	122		Sb
	51. Bismuth	210		Bi
	52. Vanadium	51·37		V
	53. Niobium	94		Nb
	54. Tantalum	182		Ta

(The "mean 76" is bracketed against 31, 75 and 122.)

Hexads.

Group	Element	Atomic Weights.	Symbols.
Chrome Elements.	*Metals.*		
	55. Chromium	52·2	Cr
	56. Molybdenum	96	Mo
	57. Tungsten	184	W
Iron Elements.	58. Magnanese	55	Mn
	59. Iron	56	Fe
	60. Cobalt	58·8	Co
	61. Nickel	58·8	Ni
	62. Copper *	63·4	Cu
	63. Uranium †	120	U

* The principal compounds of copper belong to a diad series. Strictly speaking, there is no known hexad compound of copper. A large number of the most important compounds of the iron metals belong also to a diad series.

† Uranium is doubtful—it forms a quasi-triad series, U_2O_3 corresponding to Fe_2O_3.

Chemical Nomenclature.—The names of chemical compounds have been framed upon the principle that the name of each body should not only individualise it, but as far as possible express also its composition, constitution, and relationships,—tell, in fact, its whole chemical history. It is not desirable that the whole nomenclature of a science should be frequently changed ; yet, as the scientific names express the theoretical views of their framers, an occasional partial or even total change becomes an unavoidable necessity. New compounds are also being continually discovered, whose constitution cannot be well explained by existing theories, and for which new names must be framed which do not always fit into the existing nomenclature. Chemical nomenclature must, therefore, be always undergoing modification. The changes which are made in chemical nomenclature are rarely adopted at once in those branches of science which depend upon chemistry, such as mineralogy. Within the last few years, however, the progress of chemistry has been so great, and the consequent change in chemical language so fundamental, that it has become absolutely necessary to bring the chemical part of mineralogy into harmony with the present state of chemistry.

The names of the chemical elements are trivial—that is, they are not intended to express any chemical function or quality.

When two simple bodies, or two radicles, simple or compound, combine with each other, the name of the compound body is formed of two parts, an adjective and a noun. The noun is made in the same way as the ordinary words of the language, of a root-word and a

suffix. The root consists of the essential part of the name of the most chlorous of the two radicles, and the suffix is the syllable *-ide*, having exactly the same meaning as the original English suffix, -ly. This suffix is from εἶδος, likeness. The compounds formed by the union of any given chlorous radicle with all other less chlorous radicles form a family, having the same substantive as part of their name. Thus the compounds of—

Oxygen	are called	ox-ides.
Chlorine	„	chlor-ides.
Sulphur	„	sulph-ides.

The elements oxygen, chlorine, etc., were at one time called supporters of combustion—that is, they were supposed not to be combustible themselves, but capable of forming atmospheres in which the combustible bodies could burn, the latter in turn being supposed to be incapable of forming such atmospheres. To distinguish the compounds of the two classes, a suffix was used in the names of the latter, indicative of their combustible character—viz. *-uret*, from the Latin verb *uro*. Thus, the compounds of sulphur, instead of being called sulph*ides*, were called sulph-*urets*. Although this distinction is now known to have been founded upon a misconception of the phenomenon of combustion, and that we can burn oxygen in hydrogen, as well as the converse, the term sulphuret has been so long used, especially in mineralogy, that it is likely to remain in use as a common or trivial term for several bodies.

The adjective, of which mention was made above, is used to distinguish the members of the same family. It is also formed of a root-word, consisting of the essential part, generally, of the Latin name of the basylous elements, and the adjectival suffix *-ic*, thus—

Sodium and chlorine	form	sod*ic* chlor*ide*.
Copper and oxygen	„	cupr*ic* ox*ide*.
Lead and sulphur	„	plumb*ic* sulph*ide* or sulph*uret*.

As polivalent elements can form compounds in which some of their quantivalence is latent, the same basylous elements may form several chlorides, oxides, etc. Thus, there are two chlorides of iron, two oxides of copper, etc. To distinguish those, the name of the one in which the greatest number of bonds are active terminates in *-ic*, and the other in *-ous*, thus—

Ferr*ic* chloride.	Cupr*ic* oxide.
Ferr*ous* chloride.	Cupr*ous* oxide.

In many cases it is necessary to further distinguish compounds by prefixes formed from the Greek numeral adjectives, so as to

indicate the number of atoms of one or both elements in the compounds, thus—

Iron Pyrites, $Fe^{iv}S''_2$ is Ferric *di*-sulphide.

Magnetite, or Magnetic iron ore	Fe_3O_4 is Triferric tetroxide. or $Fe''\ Fe_2'''O_4$ or Ferrous diferric tetroxide.
Braunite . . .	Mn_2O_3 is dimanganic trioxide.

Acids.—An acid originally meant any body having a sour taste, and which made certain blue colours red. A body could only possess these properties when soluble. Chemists have, however, extended the term to many other substances which are insoluble, or which, if sufficiently soluble, exhibit those qualities in a feeble degree. An acid, in its more extended sense, is a body containing hydrogen (or, according to another view, the radicle Hydroxyl, Ho), which may be readily replaced by a metal or basylous radicle. The body thus formed is termed a salt. The hydrogen which can be thus replaced is usually called displaceable hydrogen. When an acid contains one atom of displaceable hydrogen, it is called monhydric or monobasic; when it contains two, a dihydric or dibasic, etc. Dibasic, and all acids whose basicity is greater than unity, are called polybasic. Most acids contain oxygen, but some contain sulphur instead, and are distinguished by the use of the prefix *sulph-* or *sulpho-*; for example, sulphantimonous acid. Chlorine, and some other of the simple bodies, form acids by combination with hydrogen. These acids are distinguished by the prefix *hydro-*; as hydrochloric acid. As all acids contain hydrogen, this name is not strictly scientific, but is likely to remain in use as a common name.

There are certain oxides which produce acids by combining with the elements of water. Oxides of this kind are called anhydrides and sometimes anhydrous acids. When, conversely, all the hydrogen of certain acids is removed as water, we get the anhydride. An anhydride may take up the elements of water so feebly, that the acid cannot be prepared at all, although there may be numerous salts corresponding to it. Of this kind is carbanhydride, commonly called carbonic acid. On the other hand, there are acids whose anhydrides cannot be prepared.

Polyhydric or polybasic acids may form several salts with the same metal, if the quantivalence of the metal be less than the basicity of the acid. Thus, nitric acid HNO_3 forms only one salt with potassium KNO_3, while sulphuric acid H_2SO_4 can form two, $KHSO_4$ and K_2SO_4, and phosphoric acid H_3PO_4 three, KH_2PO_4, K_2HPO_4, and K_3PO_4. The salts in which some of the displaceable hydrogen still remains are called acid salts.

Polyhydric acids containing three or more atoms of displaceable

hydrogen are capable of forming intermediate acids when only partially dehydrated. The acids thus formed are called meta-acids; while those containing the maximum number of atoms of displaceable hydrogen have been conveniently termed orthic acids. Thus:—

H_3PO_4 Ortho-phosphoric acid,	−	H_2O Water,	=	HPO_3 Meta-phosphoric acid.
H_4SiO_4 Ortho-silicic acid,	−	H_2O Water,	=	H_2SiO_3 Meta-silicic acid.

Acids containing an odd number of atoms of displaceable hydrogen form a molecule of anhydride from two molecules of acid; acids having an even number form their anhydrides from one molecule, thus:—

H_2SO_4 Sulphuric acid,	−	H_2O Water,	=	SO_3 Sulphuric anhydride.
$2H_3PO_4$ Ortho-phosphoric acid,	−	$3H_2O$ Water,	=	P_2O_5 Phosphoric anhydride.
H_4SiO_4 Ortho-silicic acid,	−	$2H_2O$ Water,	=	SiO_2 Silicic anhydride.

Two or more molecules of a polyhydric or polybasic acid may form a condensed molecule by the separation of the elements of water. Thus two molecules of ortho-phosphoric acid, or rather of a soda-salt containing two atoms of the displaceable hydrogen replaced by sodium, lose a molecule of water when heated, and form what is called pyro-phosphoric acid, because produced by the action of heat, but now usually called para-phosphoric acid. Thus:—

$2Na_2HPO_4$ Disodic ortho-phosphate,	−	H_2O Water,	=	$Na_4P_2O_7$ Tetrasodic para-phosphate.

When an orthic acid gives rise to a series of condensed acids, each member of the series may in turn correspond to a condensed meta-acid. The basicity of the condensed orthic acids of a dibasic acid is equal to the sum of the basicities of the molecules condensed, less twice the number of molecules condensed upon the first. It follows from this that dihydric acids, no matter to what degree condensed, will always be dibasic, and consequently not easily formed naturally. The basicity of the orthic acids, formed by the condensation of trihydric and tetrahydric acids, gradually increases with the condensation, and octohydric and even higher acids are possible. It sometimes happens that the orthic acid is less stable than the meta-acid: thus, from analogy there ought to be a trihydric nitric acid H_3NO_4, but although there are salts de-

rivable from such an acid, the acid itself cannot be prepared. The ordinary nitric acid is the meta-acid, and the natural nitrates are meta-nitrates. Very few of the condensed acids are known, but a large number of the natural silicates are salts of such acids. When describing quartz and other natural forms of silicic acid, a table showing the relationship of the condensed silicic acids will be given.

With the exception of hydrochloric acid and chlorides, and the salts derivable from one or two sulphur acids, all the acids and salts of real importance in mineralogy and geology are oxygen compounds. The names of such acids are formed by qualifying the word acid by an adjective made as before mentioned, by adding the suffix *-ic* to the essential part of the name of the radicle. Thus sulphur yields sulphur-*ic* acid; phosphorus, phosphor-*ic* acid; silicon, silic*ic* acid. When the same element forms two acids, the name of the one containing least oxygen, or in other words the one in which fewer bonds of the radicle are engaged by hydroxyle in the acid and by oxygen in the anhydride, is formed by the suffix *-ous* instead of *-ic*. Thus sulphur, when it acts as a hexad element, forms sulphur*ic* anhydride and acid $S^{vi}O''_3$, and $SO''_2(Ho)^2$; and when it acts as a tetrad element, sulphur*ous* anhydride and acid $S^{iv}O''_2$, and $SO''(Ho^2)$.

Bases.—Certain oxides of metals, when brought in contact with water, form compounds analogous to acids, but opposite in chemical functions. Thus calcic oxide, lime, $Ca''O$, combines with water to form $Ca''H_2O_2$. Such oxides, and their compounds, with water, are termed bases—hence the term basylous given to the metallic elements. The oxides represent the anhydrous acids, and are also called anhydrous oxides; the hydrated bodies, the acids, they are usually called hydrates—the adjective qualifying the word hydrate being formed in the same way as the adjective qualifying acid. Thus KHO is potassic hydrate; slaked lime, $Ca''H_2O_2$, is calcic hydrate. As the acid hydrates are distinguished by the number of atoms of hydrogen displaceable by basylous radicles, so the basic hydrates are distinguished by the number of atoms of hydrogen displaceable by acid radicles. The monivalent metals form monhydric bases, the divalent metals dihydric bases, and so on. Polyhydric or polyacid bases, like polyhydric or polybasic acids, by losing part of their hydrogen as water, can form meta or intermediate hydrates. Thus ortho-ferric hydrate, $Fe_2H_6O_6$, by losing one molecule of water, H_2O, becomes the metahydrate found in nature as brown iron ore, $Fe_2H_4O_5$; by losing $2H_2O$, it forms a second hydrate, found in nature as needle iron ore or ordinary brown iron ore, $Fe_2H_2O_4$; by losing $3H_2O$ it becomes ferric oxide, occurring in nature as red hæmatite, Fe_2O_3; orthic aluminic hydrate, found as the mineral Gibbsite, $Al_2H_6O_6$, becomes, by losing $2H_2O$, the hydrate found naturally as diaspore, $Al_2H_2O_4$, and by losing $3H_2O$, aluminic oxide Al_2O_3.

Two or more molecules of a polyhydric base appear to be able to form condensed bases with the separation of water. Thus the first condensed orthic ferric hydrate would have the composition $Fe_4H_{10}O_{11}$; by the loss of two molecules of water this would give the condensed hydrate $Fe_4H_6O_9$, which occurs naturally as the mineral brown hæmatite, or compact and fibrous brown iron ore. We have examples of still higher condensations among the sulphur compounds, as in octoferrous sulphide $Fe_8''S''$, and in heptaferric octosulphide or magnetic pyrites, Fe_7S_8''.

Many of the anhydrous basic oxides and hydrates have been long known, and have acquired common names by which they will continue to be known, no matter what changes may take place in chemical nomenclature. Thus we have—

Systematic Names.	*Common Names.*
Baric Oxide.	Baryta.
Strontic ,,	Strontia.
Calcic ,,	Lime.
Magnesic ,,	Magnesia.
Aluminic ,,	Alumina.
Potassic Hydrate.	Potash.
Sodic ,,	Soda.

Salts.—When acids and bases mutually act upon each other—that is, when chlorous or acid radicles displace hydrogen in basyle hydrates, or basyle radicles displace hydrogen in acid hydrates, or, when acid and basic anhydrides combine—salts are formed. Salts may be conveniently classified, for mineralogical purposes, into Haloid-salts, Oxy-salts, and Sulpho-salts. Haloid-salts are such as resemble common salt in chemical constitution, hence the name. This class includes the compounds of the Halogen elements, fluorine, chlorine, bromine, and iodine with the metals,—that is, fluorides, chlorides, bromides, and iodides.

Oxy-salts are those formed by the oxy-acids, and may be divided into normal, acid, and basic salts. A normal salt is the salt which is formed when all the displaceable hydrogen of an acid is replaced by an equivalent quantity of a basylous radicle, such as a metal; or conversely, when the displaceable hydrogen of a basylous hydrate is replaced by an equivalent quantity of an acid radicle. Normal salts were at one time called neutral salts. This term was originally applied to certain salts whose solutions did not affect colouring matters. The following examples will explain more fully the meaning of normal salts:—

Nitric acid, HNO^3	$Na'NO_3$, sodic nitrate, or nitrate of sodium, or nitrate of soda. $Ca''2NO_3$, calcic nitrate, nitrate of calcium, or nitrate of lime.

Sulphuric acid, H_2SO_4	Na_2SO_4, disodic sulphate, sulphate of sodium, sulphate of soda, or thenardite. $Ca''SO_4$, calcic sulphate, or sulphate of calcium, sulphate of lime, or anhydrite. $K_2'Al_2'''4SO_4$, $24H_2O$, eikositetra-hydrated dipotassic aluminic tetrasulphate, or alum. $Fe_2'''3SO_4$, $9H_2O$, enneahydrated diferric trisulphate, or Coquimbite.
Ortho-phosphoric acid, H_3PO_4 .	K_3PO_4 tripotassic phosphate. $Ca_3''2PO_4$, tricalcic diphosphate. $Fe_3''2PO_4$, $8H_2O$, octohydrated triferrous diphosphate or Vivianite.
Ortho-silicic acid, H_4SiO_4 . . .	$Mg_2''SiO_4$, dimagnesic silicate, typical peridot, or chrysolite. $Fe_2''SiO_4$, diferrous silicate, typical eisen-peridot, or fayalite.
Meta-silicic acid, H_2SiO_3 . . .	$Mg''SiO_3$, monomagnesic silicate, typical augite, as represented by enstatite.
Condensed anhydro-silicic acid, $H_8Si_6O_{16}$	$K_2Al_2'''Si_6O_{16}$, dipotassic aluminic hexa-silicate, orthoclase, or potash felspar.

The following examples will show the character of sulphur acids and their salts better than a description—

Ortho-sulphantimonous acid, H_3SbS_3	$Pb_3''Sb_2S_6$. Triplumbic sulphantimonite, or boulangerite.
Meta-salphantimonous acid, $HSbS_2$	$Ag'SbS_2$. Argentic metasulphantimonite, or miargyrite.
Condensed sulphantimonous acid, H_4SbS_5 . . .	$Pb_2''Sb_2S_5$. Diplumbic para-sulphantimonite, or feather ore.

As acid salts are of scarcely any importance in mineralogy, what has been said on this subject at p. 20 will suffice.

Basic salts are those in which the atoms of displaceable hydrogen are replaced by a more than equivalent amount of basylous radicle or radicles. Basic salts are formed by polyatomic bases, and generally by the higher ones—like ferric and aluminic hydrates. They almost always contain the elements of water, as if the hydrates attached themselves to the acids by a limited number of bonds, thus partially retaining their character of hydrates. The following are a few examples of basic salts:—

$Cu_2''H_2CO_5$.	Dicupric carbonate dihydrate, or green malachite.
$Fe_4'''H_{12}SO_{15}$.	Vitriol ochre.
$K_2(Al_2)_3^{vi}H_{16}S_4O_{30}$.	Alunite.

Sometimes the bases do not appear to be able to remain as hydrates, and then form basic anhydrous salts—as, for instance, heterocline, which is a hexmanganic monosilicate—

$$(Mn_2)_3^{vi}\ Si\ O_{11}.$$

Some of the higher polyhydric bases, and notably the pseudo-hexatomic double atoms, aluminic, ferric, and chromic hydrates, are capable of acting as acids as well as bases. Aluminic hydrate, for instance, forms salts called Aluminates, such as potassic aluminate, magnesic aluminate, etc. The following are interesting examples of compounds of this class:—

$H_2Al_2{}'''O_4$	Diaspore.	$Fe''Al_2{}'''O_4$	Zeilanite.	$Zn''Fe_2{}'''O_4$	Franklinite.
$Mg''Al_2{}'''O_4$	Spinel.	$H_2Fe_2{}'''O_4$	Göthite, or needle ore.	$Fe''Cr_2{}'''O_4$	Chrome-iron.
$Be''Al_2{}'''O_4$	Chrysoberyl.			$H_2Mn_2{}'''O_4$	Manganite.
$Zn''Al_2{}'''O_4$	Gahnite.	$Fe''Fe_2{}'''O_4$	Magnetite.	$Mn''Mn_2{}'''O_4$	Hausmannite.

In some hydrated aluminic silicates the aluminium appears to be combined with the acid, and with bases; that is, to act the part of base and acid at the same time.

It must not be forgotten that even when we know the number of atoms in a molecule, its constitution may be represented by several formulæ, all of which must agree—1, In giving the constituents; 2, their relative proportions; and 3, the number of atoms in the molecule. The difference between the several formulæ consists in the way in which the atoms are mutually combined within the molecule. This can only be determined by studying the way in which the molecule breaks up. But as the way in which a molecule breaks up depends upon the nature of the reaction to which it is submitted, a body can have as many formulæ as there are ways in which it breaks up. Thus we may write sulphuric acid in either of the following ways: H_2SO_4, $So''_2(Ho)'_2$, SO_3H_2O. These formulæ represent a molecule of the acid; the first merely gives the numbers of the atoms of each kind in the molecule; the second attempts to do more, for it assumes that the acid consists of the diatomic radicle sulphuryl, SO_2'', combined with two atoms of the monatomic radicle hydroxyl $(Ho)'$. The third formula best expresses the separation of water from the anhydride SO_3. If we adopt the first formula, the salts are supposed to be formed by the displacement of hydrogen. If we adopt the second, the metals in the salts are still assumed to displace hydrogen, but they are further supposed to form radicles with the oxygen. Thus if potassium replaces the hydrogen, a monatomic radicle, potassoxyl, is assumed to exist in the salt; if a diatomic metal displaces two atoms of hydrogen in two atoms of hydroxyl, a diatomic radicle containing two atoms of oxygen is formed, and so on. According to the third mode, the metal may also be supposed to displace hydrogen and to form an oxide, and hence a sulphate according to the third formula would consist of the anhydrous acid and an oxide. Each formula is correct so far as it best expresses certain reactions; but as in discussing the composition of bodies it becomes necessary to select some one formula for general use, that one which best expresses the general reactions of the body, and is most in harmony

with the theoretical views of the author who uses it, is selected. The first type of formula possesses considerable advantages as being less theoretical than any other, but in many cases it does not represent the constitution of a body so well as the second. The latter is not, however, well adapted for mineral formulæ in the present transition stage of chemical notation; on the other hand, the third method is very well adapted for the purpose, because in those cases where it fails most, as in expressing the constitution of acid salts, we do not require to use it for mineral formulæ, there being very few acid salts among minerals. While the formulæ used here will generally be written according to the first method, the others will also be used whenever it may be found necessary.

In most books on mineralogy silica is considered to be a trioxide, SiO_3; even in the few in which it has been assumed to be a deutoxide, SiO_2, many of the atomic weights used are only half what they are now admitted by all chemists to be. As there is no longer any doubt that silicon is a tetrad, the formulæ of all silicates based upon SiO_3 are wrong; and when we take into consideration that the atomic weights of oxygen, sulphur, and nearly all the polyatomic metals, have been doubled, it would be useless to give the old formulæ; the best thing the student can do is to forget them.

2. Laws of Form.

If ice be heated, it melts into water; if the water be further heated, it is converted into steam or gas. The converse of these changes may be produced by cooling. As heat is only a kind of motion, the three physical states of matter depend upon the relative quantities of motion which the molecules of any given portion of it may possess. Some of the simple bodies are known in the three states; but others, such as those which form air and water, are known only in the gaseous state. Perhaps all those which occur in the solid state may be converted into gas; but the intensity of the heat required for this purpose, in the case of such bodies as carbon, silicon, etc., has hitherto been an obstacle to this being done. Many compounds, besides water, are also capable of existing in the three states; nearly all the compound bodies which exist at ordinary temperatures in the gaseous state, have been changed into liquids by cold or compression, or by their joint action, and many of them have been even frozen. But a large number of solid and even liquid compounds, the molecules of which are very complex, or the atoms of which are held together by very feeble affinity, cannot withstand the heat necessary to convert them into gas, and are decomposed into other molecules, some, or all, of which are capable of holding together under the influence of the heat-motion necessary to keep them as gases.

We have seen that sulphur is capable of forming at different temperatures two distinct molecules—one six-atomed, and the other two-atomed. Several substances, when passing from the liquid to the solid state, appear to be capable of forming distinct molecules also, which are peculiar to the solid and liquid states, or even to the solid state alone, and cannot be carried into the gaseous state. Some of those molecules appear to be chemical—that is, to be accompanied by atomic changes, which take place in atomic proportions. Others are physical, and seem to depend upon the formation of condensed molecules by the temporary association of a number of chemical molecules, unaccompanied by any atomic change, or so slight as to produce no permanent effect upon the equilibrium of the chemical molecules. The gaseous condition of matter gives us the true chemical molecule in a free state; the liquid and solid conditions may be looked upon as combinations of chemical molecules into physical molecules. The most stable physical molecules appear to assume polyhedral forms, the shapes of which depend upon the nature of the chemical molecules. When a body solidifies in such stable molecules, the whole mass obeys the action of the polyhedral molecules, and the substance is said to crystallise. Beside this crystalline state, certain kinds of solid matter appear to be capable of forming more or less intermediate unstable molecules, which do not build themselves up into polyhedral forms. The aggregation of molecules of this kind gives us solid matter, in what is called the amorphous or shapeless condition. There are two modes of this amorphism which are specially interesting to the Geologist—the glassy state assumed by bodies which pass into the solid state from the state of fusion, and the corresponding colloid, or gelatinous state assumed by certain bodies when passing into the solid state from solution. Before saying anything further upon the glassy and colloid states of solid matter, we must describe briefly the principal laws of crystallised solid matter.

Crystallology.—The term crystal is applied to any polyhedral form bounded by plane surfaces, having no re-entrant angles, and the internal structure of which is geometrically related to its external form. The study of crystals may be called crystallology, and may be divided into four parts:—1, their geometry, which is termed crystallography; 2, their formation or crystallogenesis; 3, their physical properties or crystallo-physics; and 4, the relation between the constitution of crystals and their shape or crystallo-chemistry.

Crystallography.—*Elements of Crystals.*—The bounding elements of crystals are—the faces or planes, the intersections of the faces or edges, and the points of intersection of the edges or angles. The point within the crystal from which all like bounding elements are equally distant, is called the centre of a crystal. The lines which pass

through this point from two opposite points in the surface of the crystal, are termed axes. Of the infinite number which may be supposed to pass in this way, only a limited number pass symmetrically through any given polyhedral form—that is, join opposite similar parts, such as solid angles and the centres of opposite faces and edges. The number of symmetrical axes is, therefore, determined by the number of the bounding elements of the crystal, being equal to half the number of faces, edges, and solid angles.

Axes and Sections.—Equal axes are those which join similar and equal parts. When we find in a figure an axis which is unlike any other axis in it, the crystal is called a monaxial form. In some forms every symmetrical axis may be unique. Crystals in which there is not an unique axis, are called polyaxial. A plane supposed to pass through a crystal perpendicular to a symmetrical axis, is called a section; when it passes through the centre of the crystal, and divides the axis into two equal parts, the figure of the section will be homologous with the figure of projection on a sheet of paper upon which the crystal is put, with that axis perpendicular to its surface, or, what is the same thing, to its shadow when light is held above it while in that position. Thus if a cube be placed with one of its diagonals perpendicular, its projection will be a regular hexagon.

Simple and Compound Forms.—Forms bounded by faces of the same kind, are called simple forms; those having faces of different kinds, compound forms. Compound forms are considered to be made up of as many simple forms as the crystal has different kinds of faces.

Relative Symmetry of Sections.—Sections of crystals may be classed under six categories, according to their relative degrees of symmetry:—1. The equilateral triangle and regular hexagon, and all other figures which may be symmetrically derived from them; 2. The square, which may be divided into four equal and similar isosceles triangles, and any other polygon symmetrically derived from it; 3. The rhomb and rectangle, and their symmetrical derivatives—these two figures are complementary in their symmetry, the former is equilateral, but has two kinds of angles; the latter is equi-angular, but has two kinds of sides,—a rhomb can be inscribed in a rectangle and a rectangle in a rhomb; 4. A rhomboid, which may be divided into two pair of equal opposite scalene triangles, and all other polygons of equal symmetry; 5. The deltoidal trapezium, having two unequal parallel sides, and two equal inclined ones, two pair of opposite equal angles; or the deltoid, which has two pair of contiguous equal sides, and one pair of opposite equal angles, and polygons derivable symmetrically from them; and 6. Scalene triangles.

Co-ordinate and Crystallographic Axes.—The position of the faces of a geometrical form may be determined by their relation to three

planes, or the lines formed by their intersection. These lines, which may be supposed to be of infinite magnitude, are called co-ordinate axes. If we suppose a crystal constructed about three such imaginary lines, their centre coinciding with the centre of the crystal, and the lines themselves with three of the symmetrical axes, the portion of the co-ordinate axes enclosed within the crystal would be the crystallographic axes. Every face of a crystal should actually intersect at least one of the three axes of the crystal, or do so if the face and axis were sufficiently prolonged; that is, intersect one of the co-ordinate axes, and be parallel to the other two; or it may intersect two, and be parallel to one; or, lastly, it may intersect all three. The portions of the co-ordinate half-axes intercepted between their point of intersection with each other—that is, the centre of the crystal, and their points of intersection, or possible points of intersection with a face—are called the parameters of that face. The ratio of the parameters is determined from the measurements of the angles made by the faces with each other. There are some forms whose faces can be better determined in relation to four axes.

Classification of Forms according to Number, Length, and Angle of Crystalline Axes.—The forms which are determined by means of three lines—that is, by length, breadth, and thickness—may be called triaxial forms, and those measured in four directions tetraxial forms. The triaxial forms may be divided into those in which the axes of symmetry selected as crystallographic axes are at right angles to each other, or orthic or straight forms; and those in which one, two, or the three intersect obliquely, or clinic or inclined forms. Orthic forms are subdivided into those having—1. The axes equal; 2. Two equal and the third greater or less; and 3. The three axes unequal. The clinic forms are subdivided into—1. Those in which one of the axes is inclined to a second one, but at right angles to the third; 2. Those in which one axis is at right angles to a second, but all the other angles made by three axes with each other are oblique; and 3. Those in which all the angles made by the intersection of the crystallographic axes are oblique. All tetraxial forms have three axes in the same plane, and the fourth perpendicular to them.

Crystalline Systems.—All crystalline forms whose axes belong to one of these categories, constitute what is called a *crystalline system;* all the forms in which any substance is found to crystallise, subject to a law to be described presently, constitute a *crystalline series.* The following table contains the names of the seven systems just indicated, and will help to make other relations more intelligible :—

Table of the Seven Systems of Crystals.

Triaxial Forms.

Orthic systems.	1. Monometric, isometric, cubical, tesseral, or regular system.
	2. Dimetric, mono-dimetric, tetragonal, pyramidal, or square prismatic system.
	3. Trimetric, ortho-rhombic, or rhombic system.
Clinic systems.	4. Monoclinic, mono-clinohedric, clino-rhombic, oblique prismatic, or hemi-prismatic system.
	5. Diclinic or diclinohedric system.
	6. Triclinic, anorthic, tetarto-prismatic, or doubly oblique prismatic system.

Tetraxial Forms.

7. Hexagonal, rhombohedral, or mono-trimetric system.

The systems of crystals thus marked out by the number, relative dimensions, and angles of intersection of the axes, are also distinguished by their relative symmetry. All polyaxial forms belong to the monometric system, and therefore contain several axes, giving sections of the first degree of symmetry or hexagonal axes; several of the second degree or squares, or tetragonal axes; and several giving rectangles or

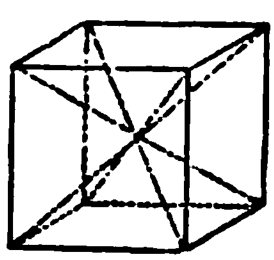


Fig. 1.

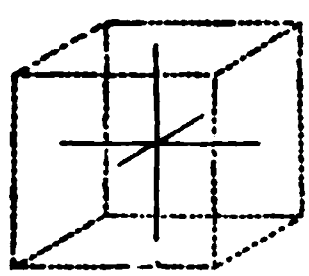


Fig. 2.

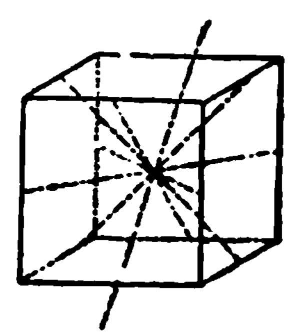


Fig. 3.

prismatic axes. Fig. 1 shows the cube with the four hexagonal axes joining the opposite solid angles; Fig. 2 the three tetragonal axes joining the centres of opposite faces; Fig. 3 shows the six prismatic axes joining the centres of opposite edges. The crystallographic axes are the three tetragonal axes. The student may at once find out, first the system, and next the crystalline axes, of many more or less well-defined crystals belonging to the orthic and hexagonal systems, by determining the sections. It is not so easy to do so in the clinic systems,—indeed it would not be possible to detect the diclinic system, or distinguish between some rhombic and monoclinic crystals, in this way at all. The tetragonal axes, although less symmetrical than the hexagonal ones, are selected as the crystallographic axes, of polyaxial or monometric forms, because they constitute a system of three equal and rectangular axes, which is just the number required.

The only other forms in which hexagonal sections could be cut are

the hexagonal, which contain one such axis, and it is the only unique axis in the system, hence the name hexagonal given to it. The other three crystallographic axes are prismatic axes. In comparing forms with one another, one of the crystallographic axes is made perpendicular, and is considered the principal axis. In the monometric or polyaxial forms, the three axes being alike, any one of them may be made the principal axis. In the monaxial system, which, like the hexagonal, has only one unique axis, this is made the principal axis.

In the dimetric system there is no hexagonal axis, and but one tetragonal one, which is the variable axis, and is made the principal one. The two equal crystallographic axes are prismatic axes. Rhombic forms have three rhombic axes at right angles, and they are selected as the crystallographic axes. As they are unequal, any one of them may be made the principal axis.* The monoclinic forms have only one rhomboidal axis, and two deltoidal. The one of the latter which is perpendicular to the rhomboidal axis, and inclined to the other deltoidal one, is made the principal axis. Triclinic forms have only scalene axes, that is, no sections can be made in a crystal belonging to the triclinic system of greater symmetry than a scalene triangle.

For the purpose of connecting the various forms belonging to a system, some simple form is taken as the type, and from it the others are then supposed to be derived. The majority select what is called the pyramid. The crystallographic pyramid is, however, a double pyramid, or two pyramids base to base. In the monometric system there is but one pyramid, the regular octahedron, a figure bounded by eight equilateral triangles (Fig. 4). As there could be only one such form in the system, its axis being the axis of a circumscribing sphere, it is not called a pyramid, but the octahedron. In the dimetric system, one axis being variable, there may be as many pyramids as possible lengths of that

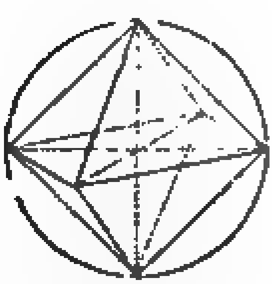


Fig. 4. Fig. 5. Fig. 6.

axis. These pyramids are obtuse when the principal axis is less than the other two axes, and acute when greater (Fig. 5). The circle shows

* The structure, cleavage, and combination of crystals serve to indicate in nature the one which should be selected. There is often great difficulty in determining the right one.

the limits of the acute and obtuse pyramids. When the vertical axis is equal to the basal ones, the pyramid would be the regular octahedron, which could not, however, occur in this system. In the rhombic system the three axes may vary; there may consequently be three series of pyramids—when the principal axis varies, or the pyramid proper; the macro-pyramids, or pyramids in which the longer of the two secondary axes varies; and brachy-pyramids, or those in which the shorter secondary axis varies. Fig. 6 represents the three kinds of pyramids drawn upon the same principal axis; the continuous lines represent the pyramid properly so called, the macro-pyramid or the pyramid formed by the variation of the longer secondary axis is represented by lines formed of short dashes and single points; and the brachy-pyramid, or pyramid formed by the variation of the shorter secondary axis, by short dashes and two points. In the clinic systems there are also several series of pyramids, which are related to each other somewhat in the same way as the rhombic pyramids, except that one or more of the axes are oblique. In studying clinic forms the pyramids are considered as combinations. Thus the monoclinic forms are considered to be made up of two hemi or half pyramids; and the triclinic of four quarters or tetarto pyramids. In the hexagonal system the pyramid has twelve sides.

The prism has also been selected as the type or fundamental form. The cube may be regarded as the prism of the monometric system. Like the regular octahedron, the cube is unique. In the other triaxial systems the typical prisms are four-sided bars, which are orthic in the rectangular and inclined in the clinic system. They are terminated by two planes called the base. A prism, unlike the cube, is in reality a compound form, and crystallographers consequently distinguish forms into closed forms, like the pyramid, and open forms, like the prism, which can only be closed by faces of a different kind called the base or pinacoid. The base may be looked upon as the section of the axis of the prism, and consequently the symmetry of any form is at once determined by that of the base of the prism. Thus, in the dimetric system, the base is a square; in the trimetric a rhomb or oblong, etc. When the variable axis of a square pyramid becomes infinite it passes into a prism; when it becomes $= 0$ it becomes a plane or base. The limiting forms of the pyramids are therefore the prisms towards which the acute series tend, on one side, and the base towards which the obtuse ones tend, on the other. In those systems in which all the axes are unequal, and may therefore vary, there are three sets of prisms corresponding with three sets of pyramids. Besides which, prismatic forms can also arise when the secondary axes become infinite.

There are seven simple forms in the monometric system; they are all closed forms, and three of them—the octahedron, cube, and rhombic

dodecahedron—are unique; but the parameters of the faces of the other four may vary within certain limits. Besides these there are six other closed forms, the faces of which have the same parameters as certain of the seven forms first mentioned, but they differ from them in having only half the number of faces. Hence these seven forms are called holohedral forms, or whole-faced forms; that is, they contain the maximum number of faces which could occur in the system with certain given parameters. The six are termed hemihedral or half-faced forms. Fig. 7 represents the hemihedral form, the tetrahedron in its relation to the holohedral form the octahedron. Fig. 8 shows the hexagonal pyramid, and its hemihedral form the rhombohedron, represented by the dotted lines.

Compound forms, as we have before said, are made up of as many forms as there are different kinds of faces. The most prominent form in a combination is called the dominant form. The combination takes place by the replacement of the edges or angles by planes. When an

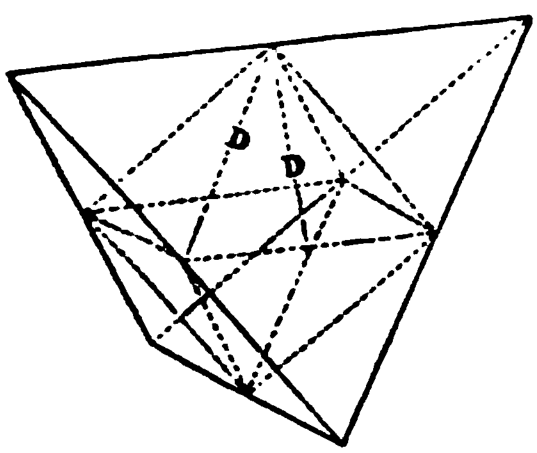


Fig. 7.

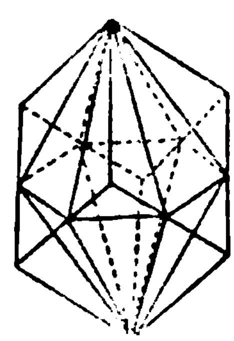


Fig. 8.

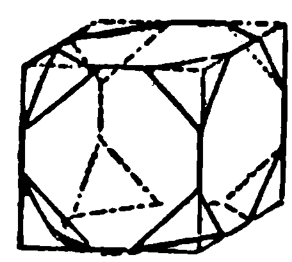


Fig. 9.

angle or edge is replaced by a single plane, it is said to be truncated; when an edge is replaced by two planes, it is said to be bevelled; when an angle is replaced by two or more planes, it is said to be pointed. The new faces which thus replace the edges or angles of the dominant form, are termed modifications, and are produced according to a definite law. Fig. 9 represents the cube with its eight angles truncated; the faces of truncation would, if prolonged until they intersected, produce an octahedron; hence such a figure would be described as a combination of the cube and octahedron, the former being the dominant form. If the truncation were carried so far that neither form could be looked upon as the dominant form, the compound would be the cube-octahedron. Fig. 10 represents the twelve edges of the octahedron truncated; the faces of truncation, if produced until they met, would produce Fig. 11, the rhombic-dodecahedron—a twelve-sided figure bounded by twelve rhombs. Fig. 12 represents the twelve edges of the octahedron bevelled. The twenty-four planes of bevelment, if pro-

duced until they intersected, would produce Fig. 13, the triakisoctahedron, or three-faced octahedron. Fig. 14 represents a four-faced

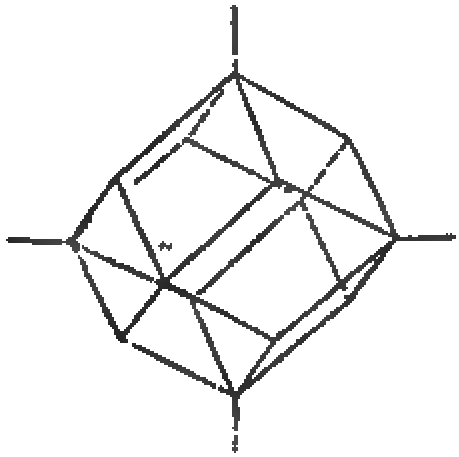


Fig. 10. Fig. 11. Fig. 12.

pointing of the six angles of the octahedron placed symmetrically on the faces. The faces of pointing, if prolonged until they intersected, would produce a twenty-four faced figure, called the deltoidal-ikositetrahedron. Fig. 15 shows the combination of the prism with the

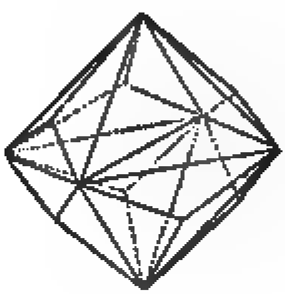


Fig 13.

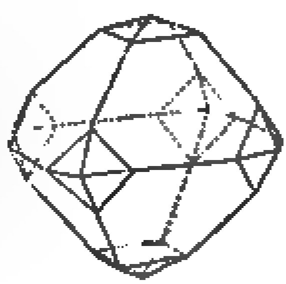


Fig. 14.

Fig. 15.

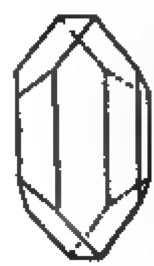


Fig. 16.

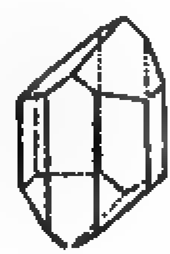


Fig. 17.

pyramid of the dimetric system. The dotted lines show the relation of the two forms. Fig. 16, representing a common form of olivine, will serve to give an idea of the combinations in the rhombic system. Fig. 17, representing the common form of augite or pyroxene, shows the character of the compounds of the clinic systems.

The following are the principal laws which have been established in Crystallography :—

1. Law of the **Invariability of the Angles of Crystals.**—This law, which was first suggested in 1688 by Dominico Gulielmini of Bologna, but first established by Romé de l'Isle, may be thus stated :—The angles of inclination of the faces of a crystal are constant and unchangeable, however unequally the faces may be developed. The corresponding angles of different crystalline specimens of the same body do not always absolutely agree. Kokscharow has measured the angles of the purest crystals of a great many minerals, and found differences frequently amounting to two or three minutes, and sometimes even to ten minutes.

2. The law of the **Parallelism of the Faces of a Crystal.**—This law, dis-

covered by Romé de l'Isle, may be expressed as follows:—Every face of a crystal has a similar face parallel to it, or every figure is bounded by pairs of parallel faces, with the exception of certain hemihedral forms.

3. The law of **Zones**, first established by Weiss, may be thus defined:—In general the faces of forms are disposed in series or zones parallel to one of the symmetrical axes, which is hence called the zone-axis. Thus, in every prism, the faces of the prism constitute a zone parallel to the axis of the prism. Faces may be in a zone which do not actually intersect on the form.

4. The law of **Symmetry**, discovered by Haüy, may be thus expressed:—1, The similar parts of crystals,—faces, edges, angles, and consequently axes, are all modified at the same time and in the same manner, and the dissimilar parts are modified separately or differently. 2, The modifications produce the same effect on the faces or edges which form the modified part when they are equal. When they are not equal, they produce a different effect. That is, if an edge be truncated or bevelled, every similar edge will be similarly truncated or bevelled; if an angle be truncated or pointed, every similar angle will be similarly truncated or pointed; and consequently every similar axis will be equally affected by the modifications. Thus the cube has eight similar angles and twelve similar edges. Theoretically we may truncate three angles or five edges; but in the physical production of crystals, if one of the angles or edges be modified, all will be similarly modified.

This, which is the most important law of crystallography, is, however, subject to an exception which was first fully formulised by Weiss. It may be defined thus:—All the similar parts of crystals—faces, edges, angles, and consequently axes—are all modified at the same time and in the same manner; or half of them, or one-fourth of them. When only half of the similar parts are modified, we get the hemihedral forms already mentioned; when one-fourth only are modified, which occurs only rarely, we get what are called tetartohedral forms. Thus, if only four of the eight angles of the cube be modified alternately, we get the hemihedral form, the tetrahedron. In the monometric system the two hemihedral forms, which each holohedral form may yield, are geometrically, and to a great extent physically, identical; but in the less symmetrical systems they are different. Delafosse * and others look upon hemihedral forms as only an apparent exception to the law of symmetry. They consider that the molecules of hemihedral forms are different from those of holohedral, and hence derive each kind of hemihedral forms from a hemihedral fundamental form. Thus, in the monometric system, the seven holohedral forms should be derived from the octahedron; the four inclined-faced hemihedral forms should be derived from one of them, the tetrahedron; the two parallel-faced hemihedral forms from one of them, the pentagonal dodecahedron. They also consider that the forms which occur in natural combinations always belong to the same type; that is, hemihedral forms never occur in combinations with true holohedral ones, or the converse, consequently when the rhombic dodecahedron, tetrakis-hexahedron or four-faced cube, and the cube, occur in combination with any of the inclined-faced hemihedral forms (and they are the only apparent holohedral ones which do), they are molecularly true hemihedral forms. Those forms could not in fact give inclined-faced hemihedral closed forms. The left and right handed form, derivable from the cube, would simply make a cube. The forms of the hexagonal system should, according to this view, be referred to six fundamental forms. If this view were adopted—and there can be no doubt that it expresses accurately the way in which combinations really do occur in nature—hemihedry would not any longer form an exception to the law of Haüy.

5. The law of the **Rationality of the Parameters of the Faces of Crys-**

* "Recherches sur la Cristallisation considérée sous les rapports Physiques et Mathematiques," par G. Delafosse, *Mém. de l'Acad. Royale des Sciences*, t. viii. des Savants Etrangers, 1848; also his *Nouveau Cours de Mineralogie*, 3 vols. 1858.

talline Series, first indicated by Malus.* If in any crystalline series one form be selected as the type or fundamental form, and its parameters be represented by $a : b : c$; then, if one of the parameters, for example c, of every face occurring in the series be assumed equal to that of the type, the others will be—

$$\begin{array}{l} ma : nb : c \\ m'a : n'b : c \\ m''a : n''b : c, \text{ etc.} \end{array}$$

The factors, m, m', m'', etc., n, n', n'', etc., which are called the coefficients of derivation, are always rational quantities, and very simple numbers, such as $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$, $\frac{2}{3}$, 1, $\frac{3}{2}$, 2, 3, 4, etc. Irrational values cannot occur. Thus the parameters, $a : b : c$ of the type or fundamental rhombic pyramid of the crystalline series of anglesite or plumbic sulphate, as determined by Kokscharow, are in the ratio of 0·77556 : 1 : 0·60894, and those of the other faces as—

$$\begin{array}{lllll} ma : nb : c & = \frac{1}{2}(0{\cdot}77556) & : & \frac{1}{2} & : 0{\cdot}60894 \\ m'a : n'b : c & = 0{\cdot}77556 & : & \frac{1}{2} & : 0{\cdot}60894 \\ m''a : n''b : c & = 0{\cdot}77556 & : & 2 & : 0{\cdot}60894 \\ m'''a : n'''b : c & = \frac{2}{3}(0{\cdot}77556) & : & \frac{2}{3} & : 0{\cdot}60894 \\ m^{\text{IV}}a : n^{\text{IV}}b : c & = \infty & : & \frac{1}{2} & : 0{\cdot}60894\,; \\ m^{\text{V}}a : n^{\text{V}}b : c & = \infty & : & \frac{1}{4} & : 0{\cdot}60894 \end{array}$$

The numerical expressions for the coefficients of derivation, m, m', ... n, n', etc., are consequently the very simple numbers, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, $\frac{2}{3}$, 2, ∞. No faces can occur on any crystal of anglesite, the ratio of the parameters of which cannot be expressed by numbers, which, like the preceding, are aliquot parts or multiples of those of the type form. The symbol ∞ implies that the distance at which the face measured along the axis a should cut that axis is infinite, or in other words is parallel to it. This beautiful law of form represents Dalton's law of multiple proportion by weight, and Gay-Lussac's law of multiple proportion in combinations by volume.

Fig. 18 represents three co-ordinate axes. The series of triangles represent a number of faces cutting the three half-axes. In order to simplify the figure, the secondary axes are supposed equal—that is, the faces to belong to the dimetric system, in which only one axis varies, while anglesite belongs to the rhombic system. The parameters, b and c, are equal, while the parameters $m\,a$, $m'a$, $m''a$, etc., are $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, etc., of c, or 2, 3, etc., times c.

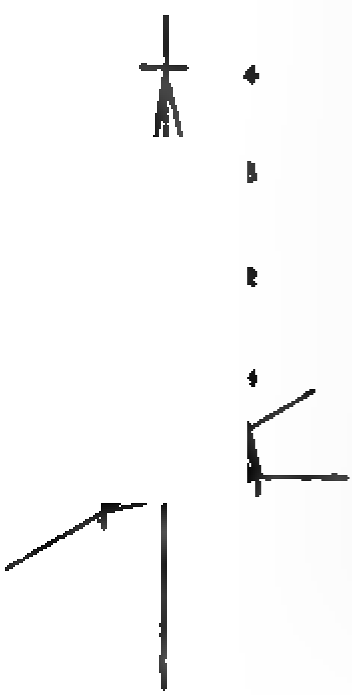


Fig. 18.

6. The Law of **Crystalline Combination.**—This law is the consequence of the Law of Symmetry, and the Law of the Rationality of the Parameters of Crystalline Series, and has been partially stated in describing those laws. It may be thus expressed:—1. A substance can only crystallise in forms, whether simple or compound, which have the same relative symmetry, that is, belong to the same crystalline system, and the parameters of the faces of which bear a simple relation to each other, that is, belong to the same series; 2. A form cannot be modified by faces belonging to a different system or a different series. There are some exceptions to the first part of this law, which will be described under Allotropy or Polymorphism.

* *Théorie de la double Réfraction de la Lumière dans les substances crystallisées.* Par E. L. Malus. Paris, 1810, p. 122.

Crystallogenesis.—Crystals can only be formed when the chemical molecules are free to arrange themselves into crystalline molecules. The processes by which they can be formed artificially, and by which there can be no doubt they were formed naturally, may be classified under three heads :—1. Solution ; 2. Fusion ; and 3. Sublimation.

Solution.—By solution is to be understood solid bodies dissolved in a substance which is permanently liquid at ordinary temperatures, such as water, which, with perhaps very few rare exceptions, is the only solvent used in the natural formation of crystals at ordinary or moderate temperatures. When a number of chemical substances, one of which predominates in mass, are fused together, the fused mass may be considered in a certain sense as a solution of those in small quantity in the more abundant one. But it will be, for obvious reasons, more convenient to confine the term solution to the result of the dissolution of solid bodies in water or other liquids.

Nearly every substance in nature is perhaps soluble to some extent in water ; but while some may be able to dissolve in their own weight of it, others require several million times as much. Again, some are capable of existing in a very soluble and also in a difficultly soluble, or what is called in practice an insoluble state, of which we shall speak under Allotropism. The separation of crystals from solutions is influenced by a great many causes, such as the temperature of the solution and the variations of temperature, hygrometric state of the air, the more or less rapid renewal of air, pressure, degree of concentration, rapidity or slowness of the evaporation, the state of repose, etc. The temperature of the solution, the depth of the solution, the surface of the containing vessel or cavity, the position where the crystal begins to form, also influence the form of the crystal, the modifications which occur on each crystal, their mode of grouping, and their imperfections. Thus, crystals formed on the surface of a solution, and which hang down in the fluid, are generally of large size, but if they are terminated by pyramidal ends, the latter are shortened and badly formed ; those which form on the bottom, and project into the solution, are generally regular, and the ends are also better formed ; those which grow on the sides, develop the upper faces more than the lower. Again, if crystals of a different substance separate afterwards, they will deposit on the previous ones in a different way, according as they grow on the bottom, sides, or top.

Crystals formed in fine non-coherent matter in suspension, do not appear to differ in form from those which grow in pure solutions. Suspended matter sometimes retards the formation of crystals. Crystals formed in deposited sediments are more regular and less modified than in pure solutions ; if, however, the solution be strong, the faces are hollowed and imperfect. The particles, when not coherent—as, for instance, fine sand—are moved in obedience to the crystallising force, and become regularly dispersed through the crystal. In this way the tessellated structure of the variety of andalusite known as chiastolite, and of some kinds of staurotide, may be accounted for. The curious concretions formed in the Fontainebleau sand by the infiltration of a solution of calcic carbonate, or carbonate of lime, in water containing carbonic acid, in which a small quantity of that salt builds up regular rhombohedrons by cementing together a large quantity of sand, is another example. The rock known as quartz rock appears to be quartz sand cemented by a small quantity of felspar. The planes of fracture, or joints of this rock, seem to be all parallel to faces of the crystalline series of orthoclase, and often give pieces which may be regarded as felspar crystals.

M. Beudant has shown that crystals formed in gelatinous matter suffer few, if any, modifications. The crystals so formed are generally isolated, well defined, and regular. This fact is of considerable geological interest. Thus we often find

doubly-terminated crystals of quartz in certain clay deposits, especially in veins which are sometimes mineralised. Their occurrence consequently proves that the clay, or clay-like mineral, had been in a more or less gelatinous state, and deposited from water.

The presence of other chemical substances in the solution also appears to influence the forms of the crystals, even where they do not combine with the body crystallising. Thus alkaline carbonates appear to cause calcic carbonate, or carbonate of lime, to crystallise in rhombic forms as arragonite at ordinary temperatures, while it crystallises in forms, of the hexagonal system, from pure solutions, under the same conditions. Alum, which crystallises usually in cubes slightly truncated on the edges, yields a combination of the cube and octahedron in nitric acid; and the cube with bevelled edges, that is with faces of the tetrakis-hexahedron or four-faced cube, in hydrochloric acid. If a salt crystallises out of a solution containing several other crystallisable salts incapable of chemically combining so as to produce a homogeneous crystal, the crystals formed are frequently modified. Thus common salt, which crystallises in cubes from most solutions, crystallises in cube octahedrons from a solution containing boracic acid, of which examples are found in nature in the Stassfurth salt-deposit. Again, some salts in crystallising have the faculty of carrying with them a more or less considerable quantity of the other salts. Leblanc obtained crystals having the form of ferrous sulphate, which contained half their weight of cupric sulphate. Beudant obtained similar crystals containing 85 per cent of sulphate of zinc; and others containing 97 per cent of sulphate of copper of zinc.

Professor T. P. Cooke of Harvard College has described a remarkable example of the same kind. Zinc and antimony form two definite crystalline alloys, $Sb_2Zn''_3$ and $Sb_2Zn''_2$. The former crystallises in long acicular prisms from a fused alloy of those metals, containing 42·8 per cent of zinc. If the quantity of zinc be gradually increased, the same kind of crystals continue to be formed, but in diminishing perfection and size, up to and even beyond 60 per cent of zinc. The most perfect crystals contained from 42·83 to 43·15 per cent of zinc. As the quantity of zinc in the mixture was increased, the proportion in the crystals increased also. Definite crystals, containing as much as 55 per cent, were obtained in this way from an alloy containing 60 per cent of zinc—that is, 12 per cent more than the normal proportion. When the percentage of zinc fell below 42, the alloy $Sb_2Zn''_2$, crystallised in broad plates, containing 33·62 per cent of zinc. These crystals were most perfectly formed in an alloy containing 29·50 of zinc. When the proportion of zinc was diminished, the broad plates were still formed, even in a mixture containing only 20·12 per cent of zinc. The crystals representing the typical formula $Sb_2Zn''_2$, could contain an excess of zinc or of antimony, the limits of those analysed being from 35·37 per cent of zinc to 24·83,—or an excess of antimony of 1·75 per cent, or of zinc of 8·79 per cent. The crystals of the typical formula $Sb_2Zn''_3$, could only crystallise with an excess of zinc, the limits of the crystals analysed being from 42·83, the normal composition to 64·15 per cent of zinc, or an excess of 21·32 per cent. Perfectly definite crystals did not, however, contain more than 55 per cent of zinc, or an excess about 12 per cent.

This chemico-mechanical association of several bodies, with the conservation of the crystalline form of one of them, is of the highest importance in mineralogy, for it shows the extent to which the chemical constitution of a crystalline species might deviate from the normal type. It proves, in fact, that a crystal may be built up of different chemical molecules, without any real chemical combination taking place. The crystal, however, is subject to modification in growing under such circumstances. Thus crystals of ferrous sulphate are rhombohedrons if mixed with cupric sulphate; rhombohedrons truncated on the hexagonal angles if mingled with magnesic or zincic sulphate; and truncated on the other angles if

mixed with aluminic sulphate. Many of the phenomena at one time attributed to isomorphism belong to this category, as was first suggested by Frankenheim. In such compound crystals the different molecules appear to be built up in regular layers in the crystals. This is shown by the fact that a very small quantity of ammonia-alum gives to common potash-alum the property of lamellar polarisation, a phenomenon due to the successive layers of the two salts. Again, minerals made up of such mixtures are usually opaque, even when the constituent bodies form transparent crystals alone. The angles of compound crystals also vary sometimes to the extent of degrees. It is especially in cleavage that the effect of mixture in crystals is most marked. It rarely happens that the planes of cleavage go through the successive layers as regularly as it does in the crystals of the pure substance. While one of the planes of cleavage may be exactly of the same character as in the latter, others are found to be uneven, unequal in lustre, and more difficult to be attained.

Microscopical investigations confirm what has been just said about mixtures in crystals. It has been found that almost all crystals contain hollows or pores, some empty, and some filled with foreign matter. These hollows are of different sizes, and though not in general regularly distributed, they sometimes occur parallel to each other within the crystal—thus showing the successive growth of the crystal. The hollows are sometimes large enough to be seen by the naked eye, but the majority are microscopic. Quartz is especially remarkable for the number of pores distributed through the whole mass of the crystal; some being not more than 0·001 of a millimetre, or the 0·00003937th of an inch. Some of the hollows appear partially filled with liquid. The existence of cavities containing liquids in rock-crystal attracted the attention even of Roman poets. Among naturalists one of the first who devoted real attention to the existence of cavities and foreign substances was Romé de l'Isle. Brewster also, by his papers on the cavities in topaz crystals, directed attention to the importance of the subject. But it is chiefly from the microscopic researches of Sorby, Zirkel, and others, that the subject has become of the highest importance to the geologist. The study of the internal structure and foreign mixtures in crystals is the surest means to determine the mode of formation of crystalline rocks. The cavities, when they contain fluids, are generally only partially full, the rest of the space being filled by gas. In some crystals the fluid is water, but carbo-hydrogens appear also to be present. In the latter case the gas may be marsh-gas. The gas in the cavities of the explosive salt of Wieliczka was shown by Dumas to contain carburetted hydrogen. Sorby has used the proportion between the space in the cavities filled by water, and that of the whole cavity, to determine the probable temperature at which the crystals were formed. While there can be no doubt that the existence of such cavities, partially filled with fluid, proves that the crystals must have been formed at a low temperature, the determinations of temperatures made with such data must be received with great caution, inasmuch as such partially-filled cavities are sometimes formed in crystals separating from even cold solutions saturated with carbanhydride or carbonic acid gas.

Crystals also often contain other minerals enclosed. The most frequent enclosing minerals or *perimorphs*, are—quartz, calcite, fluorspar, barytes, felspar, tourmaline, etc.; and the most frequent enclosed minerals, or *endomorphs*, copper pyrites, iron pyrites, göthite, asbestos, and chlorite. The term **Paragenesis** has been used to indicate this kind of association of minerals. It is only lately that its real importance has begun to be appreciated by geologists.

Fusion.—If a crystallisable simple body, like sulphur or bismuth, or some definite compound not easily decomposed by heat, be melted, and then allowed to solidify by slowly cooling, the mass will exhibit crystalline structure. If cooled rapidly, the mass will be often so compact that this structure will not be so evident. If, while the mass is solidifying, the still fluid part in the interior be rapidly

removed, the cavity left will be found full of crystals. It is in this way crystals of those bodies are obtained. The removal of the liquid portion of a crystallising mass from about the first-formed crystals could only occur in nature under very exceptional conditions. In general, where we find in nature crystallised rocks of undoubted igneous origin, the crystals have separated from a fused mass of complex composition, which acts as if it were a solution. If the unsolidified mass in which the crystals form be thick, like fused glass, the crystals will not sink through it ; and if it continues in a thick condition for a long time, at the point at which crystals can just form, large crystals may be formed which will appear scattered through a crystalline mass of a more or less different composition, which may be compact, or crypto-crystalline, or formed of an aggregate of small crystals. Such are the rocks called porphyries, some of which were so formed ; but others may never have been fused at all. Crystals separating from such a mass carry with them some of the other constituents of the fused mass, in the same way that salts separating from solution in water carry with them more or less of the other salts present. It is in this way, no doubt, that aluminous augites and hornblendes are formed in the midst of a felspar mass in true igneous rocks. At a certain stage of thickness of the fused mass it must act towards the crystals forming in it much in the same way as gelatinous deposits do to crystals formed in the wet way—namely, to produce isolated crystals of comparatively simple forms.

The experiments of Ebelmen bear out fully what has been just stated, as well as the earlier ones of Berthier. By means of fluxes, such as boracic acid, sodic silicate, etc., but especially the former, in which he dissolved the materials at the continuous high temperature which he was able to command in the porcelain furnaces at Sèvres, he succeeded in producing crystals of the hardest and most infusible substances, such as quartz, corundum, spinel, emerald, etc. These were formed sometimes by simple decomposition, with the separation of one of the new bodies in a crystalline form, just as so many compounds are formed in aqueous solutions ; and sometimes by the evaporation of the flux. Thus, on introducing a bit of lime into fused borate of magnesia, the magnesia was precipitated in transparent regular octahedrons, identical with the Vesuvian mineral periclase. M. Gaudin used sulphate of potash as a flux, and by dissolving alum in it he produced corundum.*

Sublimation.—Crystals may be formed by sublimation in two ways—First, by direct sublimation of bodies like iodine, arsenic, cinnabar, etc., or by the double decomposition of bodies in the state of vapour. M. Durocher, by acting upon the vapours of metallic chlorides by means of sulphide of hydrogen in tubes, heated between the temperature of boiling water and a dull red heat, obtained crystals of pyrites, blende, sulphuret of antimony, galena. By other reactions made in the same way, he produced magnetic oxide of iron, specular iron, and indeed most of the minerals found in mineral veins. M. Daubrée obtained analogous results by acting on vapour containing the radicle of the mineral he wished to form, heated in a tube to a white heat with steam. Like M. Durocher, M. Daubrée chiefly

* Berthier, *Annales de Chimie et de Physique*, t. xxiv. p. 363, 1823. Ebelmen, *Annales de Chimie et de Physique*, t. xxii. p. 221, 1847 ; and t. xxv. p. 279, 1851 ; *Annales des Mines*, 5me Serie, t. ii. p. 359. Hausmann, *Beiträge zur Metallurgischen Krystallkunde*, *Abhand. d. König. Gesellsch. der Wissensch. zu Göttingen*, vol. iv. 1850, 5th vol. 1852. Von Leonhard, *Hüttenerzeugnisse*, 1858. Gurlt, *Pyrogennete künstliche Mineralien*, 1857. Gaudin, *Compt. Rend.* t. xlvi. p. 765, 1857. Manross, *Experiments on the Artificial Production of Minerals*, Göttingen, 1852, and *Annalen der Chemie u. Pharmacie*, Bd. lxxx. p. 348, 1852. Breithaupt, *Die Paragenesis der Mineralien*. Söchting, *Die Einschlüsse von Mineralien*, 1860. G. Rose, *Ueber die heteromorphen Zustände der Kohlensauren Kalkerde*, *Abhandl. d. Akadem. zu Berlin*, 1856, 1858. Sorby, "On the Microscopical Structure of Crystals," etc., *Quarterly Journ. of Geolog. Society*, 1858, p. 453, and several other valuable memoirs in the same journal.

used the chlorides of the metals, but he thinks that fluorine was largely used for that purpose in nature. By this process he produced crystals of oxide of tin, brookite, quartz, apatite, and topaz. MM. Henri Deville and Caron actually produced corundum, variously coloured, and staurotide, by the mutual reaction of volatile fluorides and oxides at a very high temperature. That some minerals may have been formed naturally in this way is very probable, but before coming to a conclusion as to the mode of genesis of any given crystal, we should know its whole history. It is not enough that a given substance could be made to crystallise, by a certain process, to prove that the natural crystal was formed by that process.

The second way in which crystals may be formed, by sublimation, is indirectly by means of vapours or gases. The method of MM. Durocher and Daubrée is, to a certain extent, an example of this indirect sublimation. But the vapour of water, and indeed all vapours, have the power of transporting other substances, even solids, without exerting any action upon them. Thus boracic acid, which volatilises at so high a heat that Ebelmen was able to use it as a flux, is carried over so freely by the vapour of water, that large quantities may be distilled over in that way in a comparatively short time. It is in this way it escapes by the Suffioni, in the ancient volcanic district of Tuscany. The transporting power of superheated steam is very great, as has been shown by Mr. Jeffrey, in the case of silica, which freely volatilised in a current of steam heated to the temperature of melting cast-iron, and deposited in snow-white crystals as it cooled in the air.*

Imperfections of Crystals.—It is evident, from what has been said about the formation of crystals, that natural crystals are very seldom perfect. The chief deformities are the following:—Striation of the faces, which gives to the faces the appearance of having the surface ruled with a great number of fine lines. A face is said to be drusy when a number of very small angles of other crystals project from it, close together and in parallel position, as in some varieties of fluor-spar. Faces are sometimes rough, owing to the projection of such points, which can only be seen when it is magnified. Faces sometimes seem curved, as in tourmaline and beryl, especially from the same cause that produces striation—namely, the union of a multitude of crystals together, the faces of which are not in the same plane. In some crystals, as in chalybite, gypsum, and the diamond, there is a regular arching of the faces, which is not due to combination. Sometimes the crystal is not equally built up about the centre, so that the figure looks as if it belonged to a different system. One of the results of this deformity is, that the full number of faces which belong to a particular form may not be present, especially the combination faces. Sometimes a crystal looks as if it consisted of a frame of edges, the faces being like hoppers, each being formed by the step-wise growth of the crystalline molecules. This formation is especially remarkable in common salt, in which each face of the cube consists of a hopper or inverted hollow four-sided pyramid, the sides of which consist of a succession of steps. The deviation in the angles has already been spoken of: this deformity is so common that a distinct name, teratology, has been even proposed for its study. Perfect crystals can only be formed where the crystals grow isolated in suspension; all crystals that grow upon the surfaces of other crystals, or the walls of a druse, etc.—that is, all crystals formed in groups—must be imperfect. As prisms are combinations of endless open forms, with two planes forming the base or pinacoid, the growth of the prism may take place indefinitely in the direction of the endless axis. Each new prism or block added on may be smaller than its predecessor, by which a needle is

* Daubrée, "Recherches sur la production artificielle de quelques espèces Minérales Cristallines," etc., *Annales des Mines*, 4me Série, t. xvi. 1849, t. xix. p. 669, 1851, 5me Série, t. i. 1852; *Comptes Rendus*, t. xxxv. p. 261, 1852. Durocher, *Comptes Rendus*, t. xxxii. p. 823. Jeffrey, in *Report of the British Association* for 1840.

produced. All prisms are capable of assuming this acicular form. Or the growth of the prism may take place in the direction of the secondary axes, by which tabular or lamellar crystals may be formed. As might be expected, it is only the crystals belonging to the systems with variable axes, that are subject to these modes of growth. Sometimes crystals are bent so as to form a regular curve: quartz and beryl are often bent in this way, as if they had been subject to great pressure obliquely. Quartz crystals, and sometimes beryls, are found with one or more edges pressed flat, as if chamfered off; and some are found which, a short way above the root of the crystal, are pressed out unevenly into a thinner crystal. Like the enclosures of crystals, these imperfections are of considerable importance to the geologist in connection with petrogenesis, or the formation of rocks.

Twins.—Crystalline molecules often combine to form systems of two, three, or more, which become the nuclei of double, treble, etc., crystals. A double crystal is called a twin. Twins are sometimes classified into matagenic and paragenic the former are those in which the individual crystals have a common centre; the paragenic those in which the individual crystals have not a common centre. When a matagenic twin is composed of two half-crystals twisted half round on a common axis, it is called a hemitrope. When two crystals penetrate each other, but so that they are in different positions, it is called an inosculating twin. Thus, two cubes are often found inosculating, the hexagonal axis or diagonal of one coinciding with the tetragonal axis of another, and consequently projecting from the centres of the faces of the other. Some paragenic twins form an angle with each other, like the knee-joint; they are hence called genicular twins. Prismatic matagenic twins sometimes form Latin or Greek crosses, which are characteristic of some minerals. Some crystals are often made up of as many as six individuals. The plane along which the individual crystals of a twin join, is called the twin plane, and is always parallel to a face of the crystal, or to one which can occur in the series, and very often to that of the type or fundamental form of the series. Twin crystals, especially of those substances which occur chiefly in prismatic forms, are consequently of great value to the mineralogist.

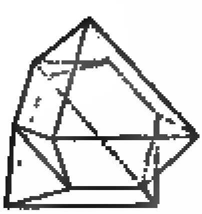


Fig. 19.

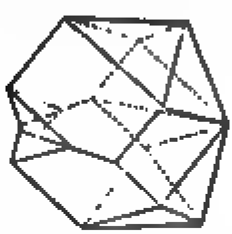


Fig. 20.

Fig. 21.

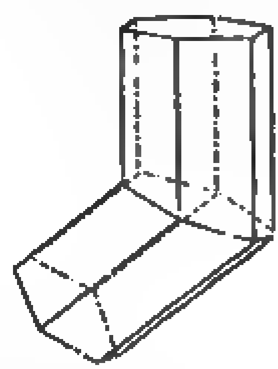


Fig. 22.

Fig. 19 is a hemitrope of spinel; Fig. 20 is a hemitrope of cassiterite, or oxide of tin; both are also matagenic. Fig. 21 is an example of an inosculating twin; Fig. 22 is a genicular twin of rutile. The twin plane is well marked in Fig. 22.

The successive building up of large crystals is sometimes shown by the layers being of different colour; or occasionally by a small crystal, often coated with small crystalline scales of some other mineral, forming a nucleus around which has grown a larger crystal in successive shells. Each shell appears to represent a period of growth which was interrupted by some cause, the fully-formed coated nucleus marking a considerable interval during which a change took place in the fluid in which the crystal grew. Fluor-spar, quartz, idocrase, and epidote, are especially characterised by this growth in successive shells. Some large crystals

seem to be made up of a regular aggregation of small crystals, in part similarly, in part differently shaped crystals of the same substance, which have grown together in parallel position. Sometimes the different forms become enclosed, so that a face of the big crystal often looks like a mosaic, in consequence of the faces of the small crystals inserted in the face having a different lustre from the rest. Large crystals of felspar and lime garnets often show this polysynthetic structure, especially when they begin to decay. This kind of combination is not to be confounded with twin-growth, which produces striæ.

The regular association of crystals just mentioned is sometimes to be found among different kinds of minerals. Among the most remarkable examples of this is the union of the crystals of kyanite and staurolite; the latter often look like a continuation or a different-coloured part of the former. Graphic granite is another example of the same phenomenon. The mineral smaragdite is a curious polysynthetic growth of hornblende and augite, first described by Haidinger.

Crystallo-Physics.—Although the physical properties of crystals, and the influence of crystalline form upon the physical forces, constitute a large part of physics, we can only refer here to a very few phenomena connected with this section of crystallology.

Optical Properties.—In monometric crystals the crystallographic axes are also axes of equal elasticity, light is refracted equally in every direction through them, and only one image is seen through them. In dimetric and hexagonal crystals, the arrangement of the molecules along the unique axis is different from that along any of the other axes. In that direction only one image is seen, in all other directions two; the ray of light is divided into two rays in the crystals; one of these rays is refracted like ordinary light, the other is differently refracted, and is called the extraordinary ray. If the crystal be rotated, the extraordinary ray rotates around the ordinary. A section of such crystals perpendicular to the unique axis, examined by polarised light between two plates of tourmaline, shows a single coloured ring with a white or black cross, according to the position in which it is examined. In crystals of the rhombic and clinic systems, in which the axes are of different length, the molecules are differently arranged along each: the molecules are always similarly arranged along equal and similar axes. In such crystals a double image is also seen, but the two rays are extraordinary, that is, neither of them is refracted like common light. Sections of such crystals cut perpendicular to an axis of symmetry, give, when examined by means of polarised light, a system of double coloured rings. In the crystals of the tetragonal and hexagonal system—that is, those having absolute unique axes—this unique axis is also the optic axis or axis of no double refraction of the crystal. But in the crystals of the rhombic and clinic systems, where there is no absolute unique axis, there are two optic axes or directions of no double refraction, which are inclined to the crystallographic axis which lies between them. By means of two plates of tourmaline, the system to which a crystal belongs may be determined at once if it be transparent. The angle between the optic axes is also of great use in distinguishing minerals.

Density.—Many substances possess the same density in the amorphous and crystalline state, but, generally speaking, the density of a body in the crystalline state is greater than in the amorphous; so that, when crystals are melted and allowed to solidify into glass, they occupy more space in the latter state than in the former. This is especially the case with the silicates, the silicon being, according to Mohr,* the expanding constituent. Quartz itself sinks from a specific

* Leonhard u. Geinitz's *Journal für Mineralogie*, 1866, p. 181; Deville, *Comptes Rendus*, vol. xl. p. 769. Bödeker, *Beziehungen zwischen Dichte und Zusammensetzung*, 1860.

gravity of 2·6 to 2·2 by melting. Magnus found red garnet from Greenland to sink from 3·90 to 3·05, and grossular from Wilui from 3·63 to 2·93; idocrase from 3·45 to 2·957.* The density of a body differs also in its different allotropic states. As a rule, the more stable form has a greater density; indeed, among minerals the only exception is perhaps that of calcite, which has a specific gravity of 2·72, while arragonite is 2·93. But octahedral sulphur 2·07, and prismatic sulphur 1·97, marcasite 4·8, and pyrites 5·1, anatase 3·83 to 3·95, brookite 4·03 to 4·085, and rutile 4·18 to 4·25, graphite 2·089, and diamond 3·55, bear out the rule.

Cleavage.—From the manner in which crystals are built up by the regular addition of molecules according to the law of symmetry, they ought to split up easier in some directions than in others. This is found to be the case. The splitting is called cleavage, the direction the cleavage-plane, and the new face the face of cleavage. In the same crystal there are several directions of cleavage; some cleavages are made with equal facility, and give faces of cleavage of equal lustre and hardness. Others are made with difficulty, and yield very imperfect faces. The directions in which crystals cleave are altogether dependent on the crystalline system, and the faces of cleavage are of considerable importance in helping to determine the fundamental form of a series. The following are the chief laws of cleavage:—

1. In the same substance the cleavages are always similarly disposed; and always form the same angles with one another and with the faces of the crystal.

2. The intersection of the planes of cleavage may always be considered, and really constitutes, an internal geometrical form called the solid of cleavage.

3. Generally the planes of cleavage are parallel to faces which exist in the crystal itself, or may occur in other crystals of the same body, according to the laws of symmetry, and of the rationality of the parameters—that is, may occur in the same series.

4. When several distinct systems of cleavage exist in a crystal, the solids of cleavage given by each system are geometrically related to each other like the forms of the crystals themselves.

Hardness.—As the hardness of bodies depends upon their cohesion, and the latter is influenced in crystalline bodies by the symmetrical construction of the crystal, the different parts of a crystal are not of the same degree of hardness. The experiments of Frankenheim and Franz have led to the establishment of the laws of this relative hardness. One law refers to the faces, and the other to the direction. The law of the faces is—Of the different faces of a crystal, those which are cut by the planes of easiest cleavage are the hardest. If several directions of cleavage of equal degree of perfection occur in a crystal, and that those directions are equally inclined to all the faces of the crystal, the faces do not exhibit any difference of hardness. Crystals of gypsum afford a good example of this law, for the faces parallel to the principal cleavages are softer than the others. The rhombohedral faces of calcite are also softer than those of the other forms in which it crystallises.

The law of direction is—Faces cut by cleavage-planes are softer in directions perpendicular to the direction of the cleavage-plane, and harder in directions parallel to it. When a face is cut by two cleavage-planes, the greatest hardness is found nearer to the most perfect. The differences of hardness between different faces of a crystal diminish in proportion as the difficulty of cleavage increases.†

Action of Solvents on Crystals.—The form of a crystal and the relative hard-

* Poggendorff's *Annalen*, vol. xxii. p. 391.

† Frankenheim, *Dissert. de Cohæsione*, 1829, and his *Die Lehre von der Cohäsion*, 1835; Seebeck, *Programm. des Cöln. Realgymnasiums zu Berlin*, 1833; Franz Pogg. *Ann.*, vol. lxxx. p. 37, 1850; Graillich u. Pekarek, *Wien. Acad. Sitzungsberichte*, vol. xiii. p. 410, 1854.

ness of its different faces influences also the action of water and saline solutions upon it, and especially the manner in which it weathers. The early experiments of Daniel showed that a ground surface of alum in which individual crystals could not be recognised, if placed downwards in water was unequally acted upon, and in a short time the surface was etched, and showed that the apparently uniform mass is really composed of a multitude of crystals cemented together by a cement of finely crystallised matter, which, being more readily acted upon than the large crystals, left them in relief. The experiments of Leydolt * with hydrofluoric acid on quartz, and with nitric acid vapours on arragonite, show that even crystals which appear to be simple are in reality complex twin combinations. Crystals of orthoclase, which look to be simple crystals, are sometimes proved by decomposition to have a most complex composition, and to be heteromeric in a high degree, often containing albite, which, decaying out, leaves a network of unaltered adularia almost transparent, while before the removal of the albite the whole mass of the crystal seems opaque. It sometimes happens that parts of a face of a different crystal may be discerned inlaid in the face of a big crystal. The face thus inlaid with other faces affords an excellent example of the unequal action of weathering and of solvents.

Weathering.—The weathering of most crystals containing water of crystallisation begins by a dull spot forming on a face. This gradually spreads in the form of a circle, or of an ellipsis, until it finally occupies the whole face. Pape,† who has investigated these figures, found that they are circles on monometric crystals, and the basal faces of the tetragonal prisms, while on the prismatic faces, and on the pyramidal faces of the same system, they are ellipses. On the faces of trimetric or rhombic crystals they are ellipses; on those of the monoclinic system ellipsoids. In the hexagonal system he found that the figures were also circles, which is not strange, considering the great symmetry of that system. These figures may be regarded as sections of a "weathering ellipsoid," which may be supposed to be circumscribed about the crystalline form. The diameters of the "weathering figures" are so related to the axes that they may be determined from the relative lengths of the latter. Pape thinks that the greatest weathering must take place along the shortest axis, because the molecular force must be less in that direction; or, in other words, that the weathering or alteration of a crystal is governed by the ratio of the axes. It is not, however, so simple as this, and is more probably governed by the cohesion or cleavages. The regularity of decomposition in the monometric system is shown by the manner in which some large rhombic dodecahedrons of lime garnet sometimes weather, so as ultimately to leave almost nothing but a framework of edges so eaten away as to show the direction of the cleavage-planes across the edges.

Crystallo-Chemistry.—*Isomorphism and Homœomorphism.*—Crystalline form is intimately connected, as Haüy always believed, with chemical composition, so that, generally speaking, different bodies have different shapes. Many cases are, however, known, where two or more bodies crystallise in the same shape. Complete identity of shape between different bodies appears, however, to be only possible in the monometric system. In the monaxial systems the forms approach; but perhaps in no instance are they absolutely identical—that is, mathematically members of the same crystalline series. There is always a slight difference in the

* *Sitzungsberichte d. Wiener Acad.* xv. 59; xix. 10. See also Sir D. Brewster, *Phil. Mag.* 1853.

† Pogg. *Annalen*, vol. cxxiv. p. 329; vol. cxxv. p. 513.

values of the angles, and consequently a slight difference in the parameters of the similar faces. Mitscherlich called the similarity of form between different bodies Isomorphism. That term is now, however, restricted to monometric forms, and the more correct term Homœomorphism applied to the phenomenon in the monaxial systems. Isomorphism and Homœomorphism include not only the idea of the same fundamental form, but also equal development of faces and zones, cleavage and hardness—that is, it includes not only external form, but also internal molecular structure. The isomorphic bodies that fulfil these conditions are found to possess equal atomic volume—a property first suggested by Kopp, Schroeder, and Dumas—and also the same atomic number. By atomic volume is meant the relative size of the atoms of different bodies, and is determined by dividing the atomic weight by the density. There are many instances, however, of two bodies crystallising in shapes which are either identical or approach very close to each other, but which do not fulfil all these conditions. Several hypotheses have been put forward to account for these anomalies, but we cannot discuss them here.

The two fundamental principles of Mitscherlich's theory of isomorphism are—1. That the forms belong to the same system, and the same, or nearly the same, crystalline series ; and 2. That isomorphic bodies, having similar functions, could replace each other in combinations without changing the forms of crystals. The converse is also assumed—that bodies possessing analogous functions are also isomorphous. Analogy of chemical formulæ does not, however, imply identity of figure, except where there is also physical analogy. Hence the faculty of chemical replacement, though still admissible, is by no means so to the extent contemplated by Mitscherlich.

Isogonism.—Laurent endeavoured to set aside Mitscherlich's first principle, that isomorphic bodies should belong to the same system, by suggesting that two bodies belonging to two different systems might be considered as isomorphic when their angles approached very closely. This opinion has been more or less adopted by several mineralogists, and the term isogonism has been applied to this modified view of isomorphism. Here the value of the angles alone is taken into consideration, and the most important of all the laws of form connected with chemical composition—the rationality of the parameters, and the general relations of the axes—are overlooked.

Heteromerism or Plesiomorphism.—The chemical replacement of isomorphic bodies has also received an important modification by Hermann's doctrine of heteromerism, or what Delafosse calls plesiomorphism. According to this doctrine, crystals may be divided into three categories :—1. Normal crystals, constituted of molecules qualitatively and quantitatively alike ; 2. Isomorphic crystals, composed of molecules represented by analogous formulæ, but containing one or more different chemical atoms ; 3. Heteromeric crystals, or crystals consisting of molecules represented by different formulæ. Hermann, as will be seen from this, does not exclude isomorphism, but he looks upon minerals like mica, garnets, tourmaline, and others, characterised by persistence of crystalline form, and variation of chemical composition within comparatively wide limits, not as chemical compounds containing isomorphic constituents, but as variable mixtures of isomorphic molecules. He also admits that molecules of different crystalline systems,

when they have the same external form, and differ very little in their angles, may enter into the composition of the same crystal. This is adopting Laurent's isogonism, but in a much more restricted sense. This classification of crystals is in perfect accordance with all the known facts of crystallology, and affords a more satisfactory and rational explanation of the anomalies of crystals than the original theory of isomorphism. When describing the minerals of the silicate class, we shall have an opportunity of explaining the doctrine of isomorphism from the point of view of the present chemical theory.*

Polymorphism.—Some bodies are capable of existing in several incompatible forms—that is, forms belonging to different crystalline series. This property is called dimorphism when the substance crystallises in two forms, trimorphism in three forms, and generally polymorphism. In most cases, the crystalline series to which the polymorphic forms of a body belong are of different systems, but sometimes they belong to the same system. Natural crystals of sulphur, and those formed from solution, have the form of the rhombic octahedron, or derivatives of it, and belong to the trimetric or rhombic system. They have a specific gravity of 2·05, and melt at the temperature of 114·5° Cent. (238·1° Fahr.); artificial crystals formed in melted sulphur are modifications of monoclinic prisms, having a specific gravity of 1·98, and a melting point of 120° Cent. (248° Fahr.) This example shows that the physical properties of polymorphic bodies are essentially different. Ferric disulphide crystallises in the monometric system as iron pyrites, having a specific gravity of 5·0 to 5·2, and in the trimetric system as marcasite, having a specific gravity of 4·65 to 4·88. Calcic carbonate crystallises in the hexagonal or rhombohedral system as calcite, having a specific gravity of 2·72, and in the rhombic system as arragonite, sp. gr. 2·92 to 2·96. Titanic dioxide affords an example of trimorphism; it crystallises in two distinct series in the dimetric system as anatase, sp. gr. 3·8 to 3·93, and rutile, sp. gr. 4·2 to 4·3; and in the trimetric system as brookite, sp. gr. 3·83 to 3·95. Polymorphism belongs to the more general phenomena of allotropism.

Allotropism—the Glassy and Colloid States.—Many substances, when melted and allowed to cool, solidify into what is termed glass. Glasses generally possess many of the physical properties of monometric crystals, except that there is no limitation of form, and above all no trace of cleavage. The density too is always less than when the same matter exists in the crystalline state. Melted glass, when dropped into water, solidifies in such a way that all the particles are in such a state of tension or strain, that if a small bit be broken off, or, if it be scratched with a file, it falls to powder with a slight explosion. The well-known toy, called Prince Rupert's Drop, is made in this way. When heated glass is cooled rapidly, it is always more or less in a state of strain, and exhibits optical phenomena somewhat similar to those of the less symmetrical crystals; but the phenomena vanish if the glass be heated and slowly cooled. When subjected

* Frankenheim, *System der Krystalle*, 1842; Buff, Kopp, Zamminer: *Lehrbuch der physikalischen und theoretischen Chemie*; Kopp, Pogg. *Ann.* vol. xlvii. p. 133; vol. lii. pp. 243, 262. *Annalen der Chemie u. Pharmacie*, 1863, cxv. 371. Schröder, Pogg. *Ann.* l. p. 552. Dana, *Silliman's Journ.* 1850, ix.; also his paper "On the Homœomorphism of Mineral Species," *ibid.* 1854. R. Hermann, *Heteromeres Mineral-System*, 2d ed. 1860. Marignac, *Ann. de Chimie*, 1862, lxix. 5. Tschermak, *Ueber die Feldspathe*, *Sitzungsberichte d. Acad. d. Wissenschaften*, *Wien*, 1865. Laurent, *Compt. Rend.* vol. xxvii., p. 134. Zehme, *Schulprogramm*, Hagen, 1850.

to pressure, similar phenomena are produced, and vanish when the pressure is relieved. In monaxial crystals, the position of the molecules, which gives rise to the optical phenomena special to each crystal, is permanent, and not relieved by cleavage ; it belongs to every part of the crystal.

Glass has no fixed melting point—properly speaking, it does not melt at all, but passes through various stages of softening. If kept for a considerable time at the point of incipient softening, it undergoes what is called devitrification, first observed by Reaumur. This consists in a passage into the crystalline state ; during the change the specific gravity increases, and there is a corresponding diminution of volume. The glassy state is, therefore, an intermediate stage of the solid state between the fluid and the true solid—that is, the crystalline state. The process of devitrification has considerable geological interest, because it is probable that most of the compact or finely crystallised basalts, diorites, etc., were formed in this way ; while such porphyries as are really of igneous origin must have been formed at a much higher temperature. When basalt is melted and allowed to cool in the air, it forms a black glass-like substance; when kept for several days at a high temperature, it begins to devitrify, small radiating crystals being formed here and there through the mass. When the whole mass is devitrified, it is not unlike the original stone.

Gums represent to a certain extent the glassy condition of other kinds of matter, and help to connect glass with the colloid or gelatinous condition of matter. Bodies that exhibit no trace of crystalline structure are said to be amorphous, and may be divided into soluble and insoluble amorphous bodies. The soluble includes two classes—namely, those that do not gelatinise, and those that do. The non-gelatinising soluble amorphous bodies may also be subdivided into two kinds :—1. Those which, like gum-arabic, dissolve in water, and may be recovered again from solution more or less unchanged ; and 2. Those which, like albumen, dissolve in water, and may be recovered with unchanged properties, provided the temperature does not exceed a certain point ; if it passes that point, the solution solidifies if it be very strong, if it be dilute the substance separates as a coagulum. The true gelatinising bodies are also of two kinds, corresponding to the non-gelatinising bodies :—1. Those which, like glue, gelatinise without becoming insoluble ; and 2. Those which, like silicic acid and other bodies, become insoluble. Graham distinguished gelatinising substances as colloid bodies ; the term has, however, been extended by its author to the whole class of soluble amorphous bodies, because all their solutions exhibit something of the character of the true gelatinising bodies, and they all possess in common, to a greater or lesser degree, the property of not being able to pass through porous bodies. The more colloid a body is, the greater is its inability to pass through porous bodies. Crystallisable bodies, or, as Graham conveniently called them, crystalloid bodies in solution, freely permeate a colloid solution and pass through porous bodies. If a solution containing a crystalloid and a colloid body be put into a vessel having a porous bottom or side, and separating the mixed solution from pure water, the crystalloid body will pass through the porous diaphragm into the water, and leave a pure solution of the colloid body in the vessel. This process of separation of the two classes of bodies, which Graham

named dialysis, is able to decompose compounds of crystalloids and colloids. Thus, when solutions of potassic or sodic silicates are dialysed, all the alkali passes away and leaves the silicic acid in solution. In this way many bodies, such as alumina and even aluminous silicates, may be obtained in a soluble state, which heretofore have been looked upon as the most insoluble bodies in nature. This property of colloid bodies offers a simple and complete explanation of many hitherto obscure phenomena of chemical geology. Among crystalloid bodies some approach the colloid class nearer than others; thus, potassic hydrate and potassic carbonate are more colloid than the corresponding soda compounds, which is perhaps one reason why soda is more rapidly removed, in the decay of minerals, than potash.

The insoluble colloid bodies of the non-gelatinising class dry down chiefly into what may be called the earthy amorphous condition; the gelatinous bodies, on the other hand, usually give, when slowly dried, more or less compact, horny, sometimes translucent or semitranslucent, masses, which in drying contract so as to produce structures in concentric or ribboned layers, such as the agates. Sometimes these layers may be in part due also to differences in composition, as is frequently shown by their being coloured differently.

Crystalloid, earthy, and colloid bodies offer a marked contrast in relation to water. Crystalloid bodies, when they form molecular compounds with water, do so in perfectly definite proportions depending upon temperature; generally speaking, the number of molecular compounds with water which the same body can form is limited to a very few, often not more than one or two. In the case of earthy bodies the combinations are perhaps all definite, but the combination is so unstable that it is difficult to draw a distinction between hygroscopic and combined water in them. Jellies, on the other hand, appear to be able to combine with water in endless proportions; it is uncertain whether any of these compounds are in definite proportions. The gradation in the power of holding molecular water, as we pass from the crystalline to the colloid condition, is illustrated by the loss of water which wounded hydrated crystals suffer. Faraday long ago noticed that the faces of crystals of Glauber salt, and other highly efflorescent salts—that is, salts which lose their water in the air—remain for a long time bright if not rubbed or scratched, but when wounded the efflorescence at once begins. The same thing takes place with the minerals called zeolites; they lose their water much more rapidly when placed over a vessel containing sulphuric acid *in vacuo*, if scratched or wounded, than if the faces be uninjured.

Bodies which are capable of existing in the crystalloid and amorphous condition are considered to be in different molecular states. This property of being able to assume different conditions is called Allotropism. Polymorphism, as was said, is but a case of it. There are apparently two kinds of it—Atomic Allotropism and Molecular Allotropism. The former is connected with differences in the atomic constitution of the molecules—that is, differences in the number of atoms, or in their relative position within the molecules. The allotropism of carbon, exhibited in the dimorphic crystalline forms, the diamond and graphite or plumbago, and in the amorphous condition by coal, charcoal, etc., belong to this kind. The colloid condition may, in some cases at least, be included in atomic allotropism. It is perhaps due to condensation of simple molecules which do not undergo by their union much disturbance of their atomic constitution. Many cases of polymorphism are undoubtedly to be included in molecular allotropism. The peculiar phenomenon termed glowing seems to belong to the allotropism of condensation, and is intimately connected with the colloid condition. When certain bodies are heated to a low redness, the temperature suddenly rises; they glow, as if a combustion was taking place in them; when cold, they are found to have contracted and become much more insoluble than before. A similar change of density and solubility occurs in many bodies unaccompanied by a glow. The

bodies subject to this are chiefly those capable of existing in allotropic states. Anatase, for instance, has, as before stated, a specific gravity of 3·8 to 3·93. When heated red hot, however, its density increases from 4·11 to 4·16, which approaches very nearly to the density of the stable form rutile. The presence in a rock of a body capable of glowing, or contracting, is a certain proof that it had not been subjected to a temperature of a red heat after the formation of the latter.

Metamorphosis.—When a body undergoes such a change in form or nature that it becomes physically or chemically different from what it was before the change, it is said to be metamorphosed. Changes of form or condition constitute physical metamorphosis; changes of nature chemical metamorphosis. The latter change is necessarily accompanied also by some physical changes. The vitrification of crystalline bodies, and the devitrification, are physical changes if they occur in homogeneous masses; but they are also chemical if they occur in complex substances. The phenomenon of paramorphosis is a purely physical phenomenon. In speaking of polymorphism, it was stated that one form of a polymorphic body was more stable than another, and that temperature determined which was the stable one; or, in other words, that one form was stable at a low temperature and the other at a higher temperature. Thus, crystals of rhombic sulphur, if heated a little above the boiling point of water, become opaque, and acquire the cleavage of the monoclinic crystals; the converse of this takes place in monoclinic crystals; for if plunged into carbonic disulphide CS_2, they suddenly become opaque with the evolution of heat, and acquire the cleavage of rhombic sulphur; the same change occurs by the influence of time,—monoclinic crystals obtained by melting sulphur sometimes become paramorphosed in a few days, sometimes only after some weeks. Paramorphosis gives us certain evidence that crystals of native sulphur must have been formed at common temperatures, and could not have been formed by sublimation, as is commonly supposed, for Frankenheim has shown that the crystals formed by sublimation, or from solution, at temperatures about that of boiling water, are monoclinic. We sometimes find arragonite having the cleavage of calcite in thermal districts, such as near Töplitz in Bohemia, and in large masses at Tolfa in Italy. It is probable that this arragonite was formed at a temperature of about 40° Cent. (104° Fahr.), from nearly pure solutions of calcic carbonate, $Ca'' CO_3$. If formed at a much higher temperature, the crystals would have been more stable; if formed at a lower temperature, it would have produced calcite; but being formed at, as it were, the turning point between the two, the crystals were unstable, and rapidly underwent paramorphosis.*

Chemical metamorphosis is the result of the action upon minerals of water holding carbonic acid and oxygen, and more or less of different salts in solution.

* The student will find much information in Professor Scheerer's *Der Paramorphismus und seine Bedeutung in der Chemie, Mineralogie, und Geologie*, 1854.

When the new mineral produced by the metamorphosis retains the outward shape of the original mineral, it is called a **Pseudomorph** or imitative form. The internal structure of a true pseudomorph has no relation with its outward form; that is, it has its own cleavage, but the form of another mineral. True pseudomorphs may be divided into two classes:—1. Pseudomorphs by alteration; and 2. Pseudomorphs by substitution. The first class may be subdivided, as suggested by Landgrebe, into:—(*a.*) Pseudomorphs formed by loss of constituents; for example, the change of bournonite, $Pb''_2Cu''Sb'''S_3$, into galena, PbS; (*b.*) Pseudomorphs formed by the gain of constituents, such as the change of galena $Pb''S$ into anglesite $Pb''SO_4$, and of red copper Cu'_2O into green malachite $Cu''CO_3Cu''H_2O_2$; and (*c.*) Pseudomorphs formed by exchange of constituents, such as the change of pyrites FeS_2 into red hæmatite Fe_2O_3, the passage of marcasite FeS_2 into green vitriol $FeSO_4,7H_2O$; calcite, $Ca''CO_3$, into fluor-spar, $Ca''F_2$; laumontite $Ca''Al'''_2Si_4O_{12}.4H_2O$, into orthoclase or potash felspar, $K''_2Al'''_2Si_6O_{16}$. The second class, or substitution pseudomorphs, are minerals formed in the moulds left by the total removal of a previous mineral, such as specular iron Fe_2O_3 in the form of calcite $Ca''CO_3$; pyrolusite, MnO_2, in the form of calcite; smithsonite, $Zn''CO_3$, in the form of calcite; soapstone, impure talc, in the form of orthoclase, $K_2Al'''_2Si_6O_{16}$; limestone in the form of common salt.*

Minerals are sometimes coated over wholly or in part with others; for instance, fluor-spar with pyrites or quartz. Minerals thus coated are sometimes, though incorrectly, included among pseudomorphs, and called mechanical pseudomorphs. The mineral enclosed in the coatings is sometimes removed by subsequent chemical action, leaving an empty mould. Occasionally this mould gets lined with a coating of new crystals, which may be the same as the coating or shell, or different; sometimes it gets entirely filled up with a mineral, forming a true substitution pseudomorph. Thus a calcite crystal has been found coated with specular iron, and the specular iron in turn coated with pyrolusite; afterwards the calcite was removed, and a hollow mould of it left in the specular iron.

The study of pseudomorphs is the true key of the chemical changes which have taken place in rocks; a single pseudomorph in a rock may often give us the whole history of its metamorphosis. The presence of numerous large pseudomorphs, in the form of the well-known hopper-like crystals of common salt, in a thick bed of limestone, gives us physical evidence of the slowness and regularity of its formation, of a far more definite and certain character than could be obtained even from fossils.

* Full information on this important subject will be found in:—Landgrebe, *Die Pseudomorphosen im Mineralreiche*, 1841; Dr. J. Reinhard Blum's *Die Pseudomorphosen des Mineralreiches*, 1843; with three Supplements, 1843-1847, 1852-1863; Volger, *Studien zur Entwicklungsgeschichte der Mineralien*—the excellent chapter on "Pseudomorphs and Metamorphic Changes on Minerals" in vol. i. (p. 222) of Dana's *System of Mineralogy*; Winkler, *Die Pseudomorphosen des Mineralreiches*, 1855; Scheerer, *Bemerkungen über Afterkrystalle*, 1856; Delesse, *Recherches sur les Pseudomorphoses, Annales des Mines*, 1859, xvi. 317; Daubrée, *Etudes et Expériences Synthétiques sur le Métamorphisme; Mémoires des Savants Etrangers de l'Academie des Sciences de l'Institut de France*, t. xvii.; Delesse, *Etudes sur le Métamorphisme, Annales des Mines*, 5me Ser. t. xii. and xiii., 1857 and 1858. The memoir of M. Daubrée, and last-mentioned one of Delesse, relate chiefly to rocks rather than to individual minerals, but they nevertheless contain much valuable information connected with this part of the subject. Bischoff's *Chemical Geology* is a mine of facts on metamorphism.

CHAPTER III.

ROCK-FORMING MINERALS.

Of the simple bodies enumerated at p. 17, several are so rare that they only occur under exceptional circumstances; others, though constituents of minerals which possess much scientific interest or practical value, do not form essential constituents of rock-forming minerals. The simple bodies of immediate interest to the geologist, and some knowledge of which is necessary in order to understand the composition, formation, and alteration of those minerals which chiefly form rocks, or which take a part in their metamorphosis, are at most nineteen in number. They are arranged in the following table in two classes, non-metallic bodies and metals.

Non-Metallic Bodies.	*Metals.*
1. Hydrogen.	10. Potassium.
2. Fluorine.	11. Sodium.
3. Chlorine.	12. Lithium.
4. Oxygen.	13. Barium.
5. Sulphur.	14. Calcium.
6. Boron.	15. Magnesium.
7. Carbon.	16. Zirconium.
8. Silicon.	17. Manganese.
9. Phosphorus.	18. Iron.
	19. Aluminium.

Non-metallic bodies form with each other, and with metals, numerous and varied compounds. Of these the only ones which enter into the composition of rock masses are those formed by chlorine, or chlorides, by oxygen or oxides, and by sulphur or sulphides. Fluorine exists in some rock-forming minerals, and one fluoride, that of calcium, takes part in the formation of mineral veins.

Oxygen is the most abundant element on the earth; it combines with all the other simple bodies, save fluorine. Oxides are consequently the most abundant and important compounds in nature. Water contains 88·88 per cent of its weight of oxygen, atmospheric air about 23 per cent; but in the atmosphere the oxygen is mixed, and not combined with the other constituent, nitrogen. Of the ten or eleven minerals which constitute the great mass of rocks, quartz contains 51·95, anorthite about 45, orthoclase about 46, albite about 47,

chlorite 46·5, talc about 49, augite and hornblende about 40, calcite 47·38, dolomite 46, and gypsum 55·45 per cent of oxygen. Nearly one-half of that part of the earth of which we have any knowledge consists therefore of oxygen.

Next to oxygen, the most abundant element is silicon ; it forms about one-fourth of the mass of the globe so far as we have any knowledge of its composition. The whole of this silicon is combined with oxygen, so that fully one half of all the oxygen in the world is in combination with silicon, and the oxide thus formed, silica, constitutes one-half the globe. If we arrange the remaining bodies in the foregoing list in the order of their abundance, they will stand as follows: aluminium, calcium, magnesium, potassium, sodium, iron, carbon, sulphur, hydrogen, chlorine, nitrogen, manganese, phosphorus, zirconium, barium, boron, and lithium. These seventeen bodies make up about one-fourth of the earth. The nineteen bodies in our list form, therefore, rather more than 99 per cent of the whole world, and the remaining forty-four elements, including all the useful metals except iron, rather less than one hundredth part.

The compounds of oxygen with the non-metallic bodies, except hydrogen, are acid anhydrides ; those with metals are generally basic anhydrides. Thus, with sulphur, it forms sulphuric anhydride, SO_3 ; with boron, boric anhydride, Bo_2O_3 ; with carbon, carbanhydride, CO_2 ; with silicon, silicic anhydride, SiO_2 ; and, with phosphorus, phosphoric anhydride, P_2O_5. With the monivalent metals oxygen forms potassic oxide, K_2O, sodic oxide, Na_2O, and lithic oxide, Li_2O ; with divalent metals, calcic oxide or lime, $Ca''O$, magnesic oxide or magnesia, $Mg''O$. The hexatomic metals, manganese and iron, form several compounds with oxygen ; thus, manganous oxide, $Mn''O$, manganic dioxide, MnO_2, ferrous oxide, $Fe''O$, and ferric oxide, Fe_2O_3.

Several of these bodies could not occur free in nature, because, owing to their active combining properties, they would, if generated, form at once new combinations with other bodies. Thus most of the anhydrides would combine with the elements of water, the acid ones to form acids, and the basic ones to form basic hydrates. Some of the basic hydrates, as well as the corresponding anhydrous oxides, are capable of existing free, but most of them combine with acids to form more stable compounds, termed salts.

The compounds of sulphur and non-metallic bodies do not occur in nature, unless we reckon arsenic among the non-metallic bodies. With the exception of the sulphides of iron, none of the sulphides of the metals in the preceding table possess sufficient stability to remain unchanged when formed in natural processes. Most of the common metals form stable sulphides, which frequently occur as ores.

The combinations of chlorine with non-metallic bodies do not

occur naturally, but the chlorides of most of the metals in the preceding table are stable bodies, and occur in nature, chiefly, however, in solution in waters.

The great agents of chemical change upon the surface of the earth being oxygen and water, the stability of bodies, and the possibility of their occurrence depends to a great extent upon their relations to those agents. Substances that do not absorb or lose oxygen readily, and are more or less insoluble in water, are consequently those which are likely to occur as minerals if their constituents are sufficiently abundant in nature. Soluble bodies, except where they occur in such masses that there is not sufficient water to dissolve them, or under other exceptional conditions, cannot occur as rock-forming minerals.

We may therefore classify the compounds of the elementary bodies in the preceding table which could occur as minerals into the following categories :—I. Metallic fluorides and chlorides ; II. Oxides—namely, 1. water ; 2. acid anhydrides and acids ; 3. basic anhydrides and hydrates ; 4. salts—namely, sulphates, borates, carbonates, silicates, and phosphates. Some of the simple bodies resist the action of oxygen and of water, and could be separated from their compounds by the natural processes in ordinary operation on the globe, and may therefore occur as minerals. Of the bodies in the preceding list, only two, sulphur and carbon, however, fulfil these conditions. Although not occurring in sufficient masses to constitute rocks, if we except the kind of coal called anthracite, which is nearly pure carbon, these bodies are so intimately connected with geological phenomena that we shall include them in the following brief description of the chief minerals which form rocks, or which characterise them, or are so intimately connected with their metamorphosis that the student should know something of their composition and properties in order to study lithology. In this description we shall confine ourselves chiefly to the general chemical constitution and relations of the minerals, especially to those points not usually treated of in mineralogical text-books. The student who wishes to study in detail the physical characters by which minerals may be distinguished, must have recourse to some special treatise on mineralogy, and examine for himself specimens of the minerals.

Minerals formed of one Simple Substance.

Sulphur.—Sulphur, as has been mentioned in a previous section, is dimorphic, but all the forms found native belong to the rhombic or trimetric system, and are rhombic pyramids more or less modified. As has been already mentioned, these crystals could not be formed at temperatures approaching that of boiling water, or be exposed to such a temperature without alteration; crystals of native sulphur must therefore have been formed at ordinary temperatures. Sulphur is found in several districts in fibrous layers of a whitish-yellow colour, as if deposited from solutions, sometimes in concretions, sometimes in beds several inches thick, as at San Fillipo in Tuscany, in the grotto of San Fedele, near Sienna, and at Canale,

near Civita Vecchia. It is also found in a pulverulent state in the lignites of Artern, in Thuringia, and Roisdorf, near Bonn, on the Rhine; in the interior of siliceous geodes at La Charité, near Besançon; and in the argillaceous marls of Montmartre, near Paris. It likewise occurs in metallic veins, particularly those of copper pyrites and galena. Crystallised sulphur is sometimes found in small geodes of mountain limestone.

Sulphur does not occur anywhere in sufficient quantity to constitute a rock, but is widely disseminated throughout rocks of different ages, either implanted in crystals, in small beds, nests, nodules, or in the pulverulent state just described, as a coating, as in some lavas, or as a cement of decomposed trachyte. It is very rarely found in basaltic districts, but occurs often in trachytic districts. In Sicily it is found associated with tertiary gypsum, limestone, and clay; at Radoboj, in Croatia, it is intercalated in beds full of remains of insects and plants, and coloured brown by mineral resin and carbonaceous matter. The latter mode of occurrence, as well as the stratified fibrous sulphur, proves the aqueous origin of sulphur.

The minerals found enclosed in sulphur are also inconsistent with its production by a high temperature, at least in a great many cases. Thus in druses in a mixture of sulphur and galena at Truskawice, in Gallicia, small crystals of sulphur are found enclosing grains of galena; small indistinct crystals enclose brown coal at Artern; beautiful crystals, enclosing indistinct scalenohedrons of calcite are found in druses of dull sulphur in tertiary marl at Girgenti, in Sicily; calcite crystals are also enclosed in crystallised sulphur in druses of limestone at Bex, in Switzerland. We have direct evidence of the deposition of sulphur from water in the mineral springs of Aix-la-Chapelle, Aix in Savoy, Saint Boës, near Dax, Bex, in Switzerland, etc. The whole of the sulphur at the latter place appears to have been deposited from water. The deposition of sulphur in some waters, as in that at Aix-la-Chapelle, is due to the decomposition of alkaline, or alkaline earthy sulphides. In volcanic regions the deposition of sulphur may result from two causes: 1. The action of oxygen on damp sulphide of hydrogen gas, or on solutions of the gas; and 2. The mutual decomposition of sulphide of hydrogen, H_2S, and sulphurous anhydride, SO_2. If the former be in excess, water and sulphur only appear to be formed; if the latter be in excess, pentathionic acid, $H_2S_5O_6$, and water are formed; the pentathionic acid is gradually decomposed into sulphur and sulphuric acid, which produces sulphates. In connection with this reaction it may be observed that several sulphates are associated with the sulphur found in districts where the sulphur is formed from gases escaping through fissures. Old craters having such active fissures, called fumaroles, are termed solfaterras.

Carbon is also dimorphic. When crystallised in the monometric system it constitutes the hardest of all the gems, the diamond. Diamantine carbon occurs in three states:—1. The true crystallised diamond; 2. The imperfectly crystallised, or knotty diamond, known as "boort," or "boart;" and 3. "carbonado" or "carbonate," a porous kind of mass which is almost glassy in some specimens, and in others almost as porous as pumice. It is of a brownish-green colour, and opaque, but often polishes of a deep black. The true diamond is usually found in very small crystals, those above a quarter of an ounce being of great rarity, while "carbonate" is often found in lumps as big as a walnut. The true diamond has been found *in situ*, in the flexible sandstone called itacolumite of the Serra do Grammagoa, in Brazil. In general, however, it is found in deposits of clay and gravel derived from the denudation of mica schists, micaceous iron slates, itacolumite, and other sandstones, and associated with grains of gold, platinum, and crystals of anatase, rutile, brookite, topaz, tourmaline, zircon, oxide of tin, titaniferous iron, magnetite, and red and brown hematite. In India it occurs in a conglomerate formed of rounded fragments of quartz, jasper, etc., cemented together by oxide of iron. The diamond district of the Oural consists of arenace-

ous rocks resting on limestones or dolomite, or diorite and syenetic porphyry. "Carbonate" was discovered in 1842 in a sandstone of the province of Bahia, in Brazil, believed to be of the same age as the gneiss and syenite of Greenland.

Brewster showed that the diamond often contains air-bubbles, and that it could not have been formed by heat. Iron pyrites and specks of gold have been noticed in diamonds, and titanic acid in their ashes. G. Rose has described a diamond discoloured by black carbon.

Graphite occurs crystallised and amorphous. The latter is the kind best adapted for making lead-pencils. This kind occurs in nests in trap, or clay slate, at Borrowdale, in Cumberland; a remarkable dyke of it, six feet wide, occurs in syenite and granite in Eastern Siberia; lumps and nests of it also occur in the crystallised limestone overlying the granite at the same place. True graphite appears to be almost exclusively confined to granite, gneiss, quartz, mica slate, crystallised limestone, and the older slates. A kind of graphite is, however, sometimes found connected with coal, especially where the latter is in contact with trap. Graphite usually contains a variable quantity of oxide of iron, silica, and other impurities. It is found in America enclosing sphene and wollastanite, and has also been noticed in skutturudite, quartz, and rhætizite, and as a pseudomorph after pyrites.

Fluorides and Chlorides occurring as Minerals.

Fluor-Spar.—Fluorine occurs in several siliceous minerals, and forms, with calcium, cerium, yttrium, sodium, and aluminium, several natural fluorides, of which only one calcic fluoride or fluor-spar $Ca''F_2$ is of sufficient importance to find a place here. Fluor-spar crystallises in forms of the monometric system, the most frequent dominant form being the cube; but perfect octahedrons are sometimes met with. It is found colourless, green, topaz-yellow, rose and crimson red, violet and sky-blue, and brown—greenish, violet blue, and wine or topaz-yellow being most frequent. It occurs chiefly in veins, often as the gangue of ores, especially of galena, in granite, gneiss, mica-slate, clay-slate, and also in mesozoic rocks.

Perimorphs.—Fluor-spar is found in common salt, quartz, pyrites, barytes, calcite, chrysoberyl, beryl, and garnet.

Endomorphs.—The following minerals are found enclosed in crystals of fluor-spar:—*Simple bodies*—silver; *Oxides*—quartz, anatase, brookite; specular iron, red ochre, bismuth ochre; *Sulphides*—pyrites, copper pyrites, marcasite, mispickel, galena, zinc blende, tetrahedrite or fahlerz, aikinite or plumbo-cupriferous sulphuret of bismuth, ullmannite or nickeliferous grey antimony, stromeyerite or argentiferous sulphuret of copper, tennantite; *Sulphates*—barytes; *Carbonates*—brown spar (dolomite), chalybite, malachite, azurite, cerussite; *Silicates*—anhydrous: hornblende; beryl; axinite; mica; adularia; euclase; tourmaline; hydrous: talc; chlorite; carpholite; lithomarge, clay; *Phosphates*—apatite; *Tungstates*—scheelite. Asphalt has likewise been found in fluor, and cavities containing liquids and air-bubbles.

Pseudomorphs.—Calcic fluoride being slightly soluble in water, especially in water containing calcic carbonate and carbonic acid, produces many pseudomorphs. It is found in the form of calcite; and the following minerals are found imitating its forms:—*Oxides*—hematite, limonite, wad, quartz; *Carbonates*—calcite, smithsonite, cerusite; *Silicates*—hydrous: chlorite, lithomarge.

Common Salt.—The only chloride of geological importance is the sodic chloride or common salt, which occurs in extensive but irregular beds in every formation from the Upper Silurian of Canada to the recent deposits now being formed in salt lakes. Rock-salt forms true rock masses, some of the beds being of great thickness. Thus at Wieliczka, in Poland, galleries have been excavated in almost pure salt from 60 to 100 yards high. This salt-bed forms part of a

series of deposits which extend along the Carpathian Mountains, and are about 500 miles long, 100 miles wide, and in some places 1200 feet thick. At Cardoña, in Catalonia, rock-salt forms an escarpment 550 feet high. Springs issuing from salt beds contain more or less salt in solution. In inland basins which do not drain into the ocean, the great reservoir of salt, especially in the great Aralo-Caspian basin, numerous salt lakes are formed. When saline water impregnates the soil it is rendered barren ; and efflorescences of salt are formed in summer as in the Russian steppes.

Common salt crystallises in the monometric system chiefly in cubes. Wherever boracic acid is present, as at Stassfurth, it crystallises in cube-octahedrons. It is sometimes found pure and limpid like glass, but is generally coloured red from intermixed clay. Sometimes it is found blue and purplish, probably from microscopic animals similar to those which make the brine produced by the evaporation of sea-water in "salt gardens" blood-red, when it attains a certain degree of concentration.

Salt is generally associated with anhydrite and gypsum, sandstone and carbonate of lime. Other salts also occur associated with it, such as polyhalite, a heteromeric compound of calcic, magnesic, and potassic sulphates. At Stassfurth, in Prussia, it is associated with compact boracite and magnesic sulphate, one molecule of which, with about ten of common salt, forms a heteromeric mineral called martinsite. The association of boracite is interesting, because in the Asiatic steppes borax lakes appear to occur in the district of the saline lakes. In the salt lakes, about the mouth of the Volga, a compound of sulphate of soda and sulphate of magnesia called *astrakanite* is formed in winter ; a similar mineral called *bloedite* is found in some salt beds. At Villà Rubia, in Spain, glauberite, a compound of the anhydrous sulphates of lime and soda, occurs in the salt. The bloedite indicates perhaps a low temperature, and the glauberite a high temperature, during the deposition of the salt.

Endomorphs.—Besides the substances just mentioned, crystals of anhydrite, gypsum, fluor-spar, and copper pyrites, occur enclosed in salt. Cavities filled with a fluid, and some containing air-bubbles, are also found in salt. The explosive salt of Wieliczka contains compressed gas composed of hydrogen, carbonic oxide, and olefiant gas.

Pseudomorphs. — Common salt occurs as a pseudomorph of anhydrite and gypsum. Gypsum and polyhalite also occur in the form of salt. But the most curious and important pseudomorph of salt is one in the form of dolomite. Of the pseudomorphs of other minerals in the shape of salt the most interesting are—limestone and sandstone. The replacement of salt by limestone appears not to have been confined to single crystals, but to have extended to whole beds.

Oxides occurring as Minerals.

Silicon is, after oxygen, the most abundant simple body forming the materials of rocks. It exists as **Silica**, or silicic anhydride, SiO_2, as silicic hydrates or acids, and as numerous salts called silicates. Silicon being quadrivalent, its normal or orthic acid should be $SiO_2, 2H_2O$, or H_4SiO_4, or $Si(Ho)_4$. The meta-acid should be SiO_2,H_2O, or H_2SiO_3, or $SiO(Ho)_2$. Ortho-silicic acid is not definitely known, but many natural silicates represent it. Meta-silicic acid can be readily obtained by the evaporation of a dialysed solution of silica. Many silicates contain condensed silica, and some of the corresponding acids are known, thus the para-acid $H_6Si_2O_7$ was obtained by Ebelmen from silicic ether. Others, such as $H_4Si_3O_8, H_2Si_3O_7$, etc., were obtained by Doveri, Fuchs, Sullivan, etc. As the true constitution of the silicates cannot be understood without some previous knowledge of condensed silicic acids, a table is added here to show the relation of the condensed silicic acids, and consequently the silicates, which are theoretically possible. The acids in each vertical column differ by H_2SiO_3, or a multiple of it, from those above or

below them in the same column; that is, the successive condensations are effected by the addition of a molecule of meta-silicic acid. This relationship is analogous to that offered by the homologous series of carbon compounds, and we may conveniently call the silicic acids so differing homologous acids. The acids in the same horizontal line have an equal number of silicon atoms, and differ by one or more molecules of H_2O. They might, after the analogy of carbon compounds, be called isologous acids. All the acids in the second column, or those homologous with meta-silicic acid H_2SiO_3, are simple multiples of that acid, that is, they are polymeric. All simple silicates and all complex silicates, in which there is true isomorphic replacement, find their place in such a table. Heteromeric combinations, that is minerals formed by mixtures of different silicates, cannot of course be included, nor those in which alumina acts both as a base and acid.

Orthic Acids.	*Meta-Acids.*	*Anhydro-Acids.*	
H_4SiO_4	H_2SiO_3	SiO_2	
$H_6Si_2O_7$	$H_4Si_2O_6$	$H_2Si_2O_5$	Si_2O_4
$H_8Si_3O_{10}$	$H_6Si_3O_9$	$H_4Si_3O_8$	$H_2Si_3O_7$
$H_{2n+2}Si_nO_{3n+1}$	$H_{2n}Si_nO_{3n}$	$H_{2n-2}Si_nO_{3n-1}$	$H_{2n-4}Si_nO_{3n-2}$, etc.

It has not been thought necessary to carry the series beyond three. The last formula in each vertical or homologous series is a general formula for the whole series in which the co-efficient n stands for any simple number.

All condensed orthic acids may be considered to be compounds of the normal orthic acid H_4SiO_4 with the meta-acids; all condensed meta-acids are multiples of the normal meta-acid H_2SiO_3; all condensed anhydro-acids are combinations of meta-acids with the anhydride SiO_2. The molecules of the condensed orthic and anhydro acids are consequently made up of two different kinds of molecules, the molecules of the meta-acids of only one. This will be better understood from the following table, which shows the constitution of all the isologous acids containing six atoms of silicon:—

			Meta-acids.		Orthic acid.
Orthic Acid . .	$H_{14}Si_6O_{19}$	=	$H_{10}Si_5O_{15}$	+	H_4SiO_4
Meta-Acid . .	$H_{12}Si_6O_{18}$	=	$6H_2SiO_3$		
					Anhydride.
Anhydro-Acid .	$H_{10}Si_6O_{17}$	=	$H_{10}Si_5O_{15}$	+	SiO_2
	$H_8Si_6O_{16}$	=	$H_8Si_4O_{12}$	+	$2SiO_2$
	$H_6Si_6O_{15}$	=	$H_6Si_3O_9$	+	$3SiO_2$
	$H_4Si_6O_{14}$	=	$H_4Si_2O_6$	+	$4SiO_2$
	$H_2Si_6O_{13}$	=	H_2SiO_3	+	$5SiO_2$

This table shows why, on the one hand, we do not often find free quartz associated with ortho or meta silicates, while on the other it is very generally associated with anhydro-silicates. Thus anorthite, nepheline, leucite, and augite, scarcely ever occur in rocks containing free quartz; while the anhydro-silicates, orthoclase, and albite, always occur, as in granites, with abundance of it.

Silica in one state is very soluble in water, and a pure solution of it may be obtained by dialysis; it becomes insoluble after it has once gelatinised. In the nascent state it dissolves more or less freely in acids, but after it has gelatinised or precipitated, it becomes very sparingly soluble. Thus it is readily soluble in hydrochloric acid when silicates are decomposed by that acid; the sulphuric acid formed by the natural oxidation of pyrites dissolves a considerable amount of silica, when it acts on clays and slates, etc. Even carbonic acid dissolved in water appears to possess this power, especially when it acts on argillaceous limestones. This explains the presence of silica in river and spring waters. This silica, whether present as a free acid or as a calcic silicate, is precipitated along with the carbonates, when the water is boiled, or when it evaporates in lakes, or in the ocean. Under

considerable pressure, and at high temperatures, silicates are decomposed by alkaline or acid solutions, and the silica dissolved more freely than under ordinary pressure.

Silicic anhydride may be melted into a viscid transparent liquid by the oxy-hydrogen blowpipe; on cooling, it solidifies into a glass which is readily acted upon by alkaline solutions. Crystallised silicic anhydride has a specific gravity of 2·6, that of the glass of melted silica 2·2, amorphous silica 2·1. These differences are of great importance in connection with the igneous origin of granite and other crystalline rocks, inasmuch as we ought sometimes to find glassy silica in rocks if they had been in a state of igneous fusion.

Quartz.—Natural silicic anhydride is the mineral *quartz*. The usual crystalline form of quartz is a hexagonal or six-sided prism, pointed, when complete, at both ends by hexagonal pyramids. Doubly terminated crystals are, however, uncommon, and appear, as has been already pointed out, to be formed in gelatinous masses. The forms are very simple, if we pay no attention to the small faces, but owing to the number of the latter, the distinct faces which can occur in the quartz series are numerous. M. Descloizeaux has pointed out the existence of more than 150 modifications. Quartz minerals belong to three categories:—1. Crystallised quartz or rock-crystal; 2. Uncrystallised or crypto-crystalline or chalcedony; and 3. Hydrated quartz.

1. *Transparent Crystallised Quartz or Rock-Crystal.*—The smaller crystals are commonly known as Irish diamond, Bristol diamond, etc.; large masses are called "pebble," and are used for lenses of spectacles. When coloured violet it is the common *amethyst;* the latter, however, has also some peculiarities of crystalline structure. The brown and blackish coloured variety of quartz is called smoked quartz or Cairngorm stone, from the name of a mountain in Scotland. The term "Cairngorm stone" has, however, in practice a much wider extension, being applied to stones of all shades of colour, from pale yellow to black. The rich yellows known as *citrin* are rare, but are imitated by burnt amethysts; the yellowish-brown are called *cinnamon* or *pierre de canelle*—these names, however, belong more properly to a variety of garnet. The black are also called *morion*. *Rose quartz* is seldom found in distinct crystals, and is usually only semi-translucent. *Common quartz* is the name given to all opaque, colourless, or partly coloured crystals and crystalline masses, such as that forming veins in other rock, and distinguished as *vein quartz*.

2. *Uncrystallised or Crypto-crystalline Quartz.*—Under this category may be included all the minerals which represent the passage of quartz from the colloid to the crystalloid state. Under this category come the great variety of minerals which receive the collective name of *chalcedony*. They are colloid quartz, which has slowly solidified, and as it did so began to pass into the crystalloid state. Indeed, according to Fuchs, they are mixtures of amorphous and crystallised quartz, the former of which may be removed by caustic alkalies. They are all semi-transparent or translucent. *Chalcedony* is derived from Chalcedon, an ancient city of Asia Minor, now the village of Kadi-Kioi near Brusa. In a more limited sense it is applied to the opalescent greyish-blue or yellowish non-crystalline quartz, which occurs in stalagmitic and stalactitic, botryoidal, nodular, and reniform masses in hollows, often covering over minerals of the most different kinds. It sometimes occurs in thin bands. In some Indian stalactites the roots are chalcedony, but towards the end the colloid silica became crystalline and formed quartz crystals, which in some specimens have trihedral summits. *Carnelian* (from *caro*, flesh) is a chalcedony of a bright red, sometimes of a yellowish-red and white colour, the colours being due to ferric oxide. *Chrysopras* (from χρυσὸν πράσον, golden leek) is chalcedony coloured green by nickel. *Plasma* (πλάσμα, anything moulded in soft material) is a dark or leek green, faintly translucent, chalcedony. If bright red spots occur in it, as if from intermixed carnelian, it is called *heliotrop*. *Onyx*

(from ὄνυξ, the nail of the finger) is a chalcedony composed of two or three differently-coloured layers. When one of these is of a deep brown colour, and covered with a thin bluish-white layer, it is the *onicolo* or *nicolo* used for cameos, the brown layer forming the ground, and the figure being cut out of the white layer; when the layers of onyx are concentric, the centre being brown and surrounded by a white ring, they are called, when cut, *eye-stones*. Fine reddish-brown or liver-coloured chalcedony is called *sard*, from the ancient Sardis in Lydia, or, as some think, from σάρξ, raw flesh. Alternate layers of carnelian and opalescent chalcedony constituted *sardonyx*. *Agates* (from the river Achates, in Sicily, where they were first found) are concretionary masses of all the preceding, deposited in layers one upon the other, usually in hollows in volcanic rocks. These concretions are due to the dialysis of solutions of silicates, the crystalloid bases going away through the porous stone. When cut across, the sections of the agates show the layers. Sometimes the centre consists of a mass of radiated amethyst crystals, or of colourless crystals, having the structure of amethyst. Sir David Brewster estimated as many as 17,000 layers in an inch of one specimen of agate. The term *jasper* is now applied to impure opaque quartz masses, found as concretions like flints, or in layers in other stones. The usual colours are various shades of red, but green and yellow colours are also frequent. When the colours occur in alternate layers it is called *striped* or *riband jasper*. The impurities are chiefly silicates of alumina and iron. In most limestones concretionary masses of silica occur. In the older rocks these concretions are termed *hornstone*, or *chert*; in the chalk they are *flints*, which, according to Ehrenberg, consist for the most part of the remains of infusoria. Similar masses, almost identical with flints, occur in the Jura limestone. In the tertiary beds of Paris the flints are represented by a hydrated silica *menilite*, which is also infusorial. It is probable that some of the hornstones of the carboniferous limestones are also of organic origin; but that all are not so is proved by the partial conversion of fossil corals into hornstone—a fact which shows that the hornstone is due to a subsequent pseudomorphosis. *Lydianstone*, *touchstone*, or *basanite*, is simply a jasper-like siliceous rock coloured by charcoal, which, on account of its hardness, is used as a touchstone for gold. *Granular quartz* or *quartz rock*, *itacolumite*, *buhrstone*, *kiesel-schiefer* or *phthanite*, and the various *sandstones*, though consisting almost entirely of silica, are true rocks, and their description belongs to the next section of this Manual.

3. The facility with which hydrated silica loses water prevents the formation of great masses of minerals composed of hydrated silica. The term *opal* may be applied to all compact uncrystalline semi-translucent to opaque hydrated silica, containing from 3 to 13 per cent of water, and a specific gravity of from 1·9 to 2·3. They are obviously solidified gelatinous silica. When of a milk-white colour, opalescent, and exhibiting a rich play of colours, it is the *noble opal*. When not opalescent, it is *common opal* or *halb-* or *semi-opal*. When porous and opaque, but becoming transparent in water, it is called *hydrophane*. When nearly opaque, of a bluish-white porcelain colour, and adhesive to the tongue, it is called *cacholong*. *Wood opal* is simply silicified wood. Sometimes the structure is perfectly preserved, at others it is almost obliterated, and presents in the same specimen all the graduations from the milk-white of semi-opal to the brown of *menilite* already mentioned.

Besides the opals proper there are several other hydrous siliceous minerals of interest, among which may be mentioned:—1. The glassy variety called *hyalite*. 2. The *sinters*, or loose deposits from waters, which occur sometimes as porous stalactitic, botryoidal, fibrous, etc., masses; and sometimes in compact masses, and called *siliceous sinter* or *Geyserite*, from the Geysers of Iceland: *fiorite*, or *pearl sinter*, found in shining globular and botryoidal masses in cavities of volcanic tufa. Another variety of this mineral, having a specific gravity of 1·88, and containing 16·35 per cent of water, representing the anhydro-acid $H_4Si_3O_8$, has been named *michaelite*, from St. Michaels in the Azores, where it occurs as a white

pearly fibrous mineral. 3. The earthy deposits, such as *Randanite*, and the friable white deposit from above the Upper Green Sand, described by Way. Randanite, which derives its name from Randon, in the Puy de Dôme, where it was found, consists of the casts of infusoria. It is probable that most, if not all, hydrous siliceous earths are of organic origin.

The minerals enclosed in crystals of other minerals, or what we have for convenience called *endomorphs*, the enclosing minerals themselves, or *perimorphs*, and the imitative forms which minerals assume when they fill the place of decayed minerals, or are produced as the result of that decay by the addition to or loss of some of the materials of the original minerals, or *pseudomorphs*, afford us the most valuable and trustworthy evidence of the genesis and metamorphoses of minerals, and of the rocks which they form. Their study puts an end to many crude theories and unscientific guesses as to the mode of formation of rocks. Few minerals afford so numerous and instructive examples of each class as quartz, and for this reason we think it desirable that the student should possess as complete lists of them as possible.

Endomorphs, or enclosed minerals, observed in quartz crystals.—*Non-Metallic Bodies:* sulphur, graphite, anthracite. *Metals:* gold, silver, copper. *Halogen compounds:* fluor-spar. *Anhydrous metallic oxides:* rutile, anatase, brookite; specular iron, magnetite, micaceous iron, red oxide of iron; pyrolusite; oxide of tin or cassiterite; bismuth ochre. *Hydrates:* limonite or brown hematite, göthite (pyrrhosiderite, onegite, needle iron ore, etc.) *Sulphurets:* pyrites, pyrrhotine or magnetic pyrites, marcasite, mispickel, chalcopyrite or copper pyrites, erubescite or variegated copper, galena, blende, manganblende, cinnabar, molybdenite, stibnite or antimony glance, zinkenite, heteromorphite or feather ore, pyrargyrite or ruby silver, tetrahedrite or fahlerz, stephanite or brittle silver, silver glance. *Tellurides:* foliated tellurium or nagyagite. *Sulphates:* barytes, anhydrite. *Phosphates:* pyromorphite. *Arseniates* (hydrous): erythrine or cobalt bloom. *Carbonates:* dolomite, calcite, chalybite, magnesite. *Silicates* (anhydrous): augite (?), hornblende (amianth, asbestus, grammatite, actinolite, byssolite), acmite; beryl;—garnet; epidote, thallite; axinite;—mica;—orthoclase, albite;—topaz, lievrite; sphene or titanite; tourmaline. *Hydrous silicates* (magnesian): talc; chlorite; (non-magnesian) calamine, carpholite; clay;—and the zeolites,—chabazite; stilbite. *Titanates*, ilmenite, crichtonite; *Tungstates*, scheelite, wolfram.

Besides these, quartz crystals contain asphalt, basalt, and granite. Most quartz crystals contain cavities, some of which contain water, oil, and bubbles of air. Some of these cavities contain loose crystals, or a minute grain of sand. Sometimes the cavity is so filled with crystals that their form cannot be determined. When their forms can be observed they are found to be cubes, prisms, etc. The quartz crystals when crushed yield traces of chloride of sodium, calcic sulphate, etc. The air-bubbles are often so numerous that the crystal becomes opaque. In vein-quartz the air-bubbles are often not more than $\frac{1}{1000}$th of an inch apart, so that a thousand millions of them exist in a cubic inch.

Quartz crystals frequently enclose other crystals of quartz. Sometimes the enclosed quartz is coated with crystals of other minerals, such as chlorite. Again, a series of planes can be noticed, parallel to some face, generally the terminal pyramidal planes, indicating successive stages of growth. Occasionally we have evidence of a change in the conditions of growth of the crystal between the deposition of one layer or shell and the others. Thus we find the interior of crystals perfectly transparent, while the other is perfectly opaque and white from air-bubbles, showing that the solution in which the last layer was formed contained gas. More rarely, an outer layer of transparent quartz covers the opaque one. This phenomenon may also be seen in fluor, there being sometimes two or three opaque layers alternating with transparent ones.

Perimorphs, or crystals enclosing quartz crystals.—*Metals:* gold. *Fluorides:* fluor-spar. *Oxides:* tin stone. *Sulphurets:* pyrites, galena, tetrahedrite or

fahlerz, skutturudite or ansenikkobaltkies, molybdenite, cobaltine, pyrargyrite or ruby silver. *Sulphates:* barytes, gypsum. *Borates:* boracite. *Phosphates:* apatite. *Carbonates:* calcite, chalybite, smithsonite. *Silicates* (anhydrous): hornblende, beryl, garnet, idocrase, mica, orthoclase, sanidin, albite, topaz, kyanite, tourmaline; (hydrous) clay or halloysite or bole, apophyllite, heulandite, praseolite or hydrated iolite or cordierite. *Chromates:* chromate of lead, tungstates, scheelite.

Pseudomorphs.—*Quartz* in the form of: *Fluorides:* fluor-spar. *Oxides:* corundum, oxide of iron. *Sulphurets:* pyrites, galena. *Sulphates:* gypsum, anhydrite, barytes. *Carbonates:* calcite, bitter-spar, chalybite, baryto-calcite, cerusite, smithsonite, diallogite. *Silicates:* scapolite (andalusite—?), augite, garnet, prehnite, heulandite, stilbite, natrolite, calamine. *Phosphates:* pyromorphite. *Tungstates:* scheelite, wolfram. *Eisenkiesel* in the form of: calcite. *Chalcedony* in the form of: fluor-spar, calcite, bitter-spar, barytes, pyromorphite, datholite. (Carnelian, chalcedony proper, and prase, occur in the form of calcite.) *Hornstone* in the form of: fluor-spar, calcite, chalybite, mica. *Semi-opal* in the form of: calcite. *Jasper* in the form of: hornblende. *Other minerals* in the form of *quartz:* hematite, limonite, pyrites, steatite, chlorite.

Corundum, or native aluminic oxide or **Alumina,** Al_2O_3, crystallises in six-sided prisms and pyramids. When transparent, and coloured blue, it is the sapphire; when red, the ruby, the most valuable of all gems; when green, the oriental ruby, one of the rarest gems. *Emery* is an impure corundum, containing ferric oxide. Alumina can be obtained by dialysis in a soluble state; in its ordinary condition it is one of the most insoluble bodies known. In the flame of the oxy-hydrogen blowpipe alumina melts into a viscid liquid, which solidifies into a transparent glass. The normal hydrate of aluminium is $All(Ho)^6$,* $Al_2(Ho)^6$ or $Al_2O_3, 3H_2O$; it occurs in nature as the mineral *gibbsite* or *felsöbanyite*,† and crystallised as *hydrargyllite*. The meta-hydrate, $AllO_2(Ho)^2$, $H_2Al_2O_4$, or $Al_2O_3H_2O$, also occurs in nature as the obscurely crystallised mineral *diaspore*. The latter mineral is found in chlorite slate, and also accompanies emery. There is also an opaque amorphous hydrate containing ferric hydrate, called *bauxite*. Alumina forms salts called aluminates, corresponding to the meta-hydrate, $H_2Al_2O_4$. The most important of these are the spinels: $Mg''Al_2O_4$, the magnesian spinel, or balas ruby, $Zn''Al_2O_4$; gahnite, the zinc spinel, $Fe''Al_2O_4$; Hercinite, or the iron spinel. If glucinium be a bivalent metal, the chrysoberyl should have the formula $Be''Al_2O_4$, analogous to the spinels, with which it agrees also in form. Besides the numerous aluminous silicates, in some of which the alumina appears to act the part of acid as well as base, and the sulphates or alums, aluminium forms the interesting halogen mineral cryolite Na_3AlF_6, or $Na_6Al_2F_{12}$.

The observations of Brewster on Brazilian chrysoberyls are important in connection with the genesis of minerals.‡ He found layers full of cavities containing liquids different from water. In one crystal he observed two parallel layers, in one of which he observed not less than 30,000 such cavities in about 1-7th of a square inch. Sometimes the cavities contained two fluids which did not mix. He noticed in some cases that the fluid deposited dark matter which appeared cellular, as if of organic origin. Some layers contain cavities filled with fluids without any air-bubbles.

Oxides of Iron—Two oxides of iron occur as minerals—ferric oxide, commonly called sesquioxide or peroxide of iron, Fe_2O_3, and ferrosoferric oxide, Fe_3O_4 or $Fe''Fe'''_2O_4$. Ferric oxide occurs in several states,—crystalline, massive, earthy,

* The symbol All is used for the double atom Al_2, which occurs in all natural aluminous compounds.

† The name gibbsite is sometimes applied to a phosphate of alumina also.

‡ *Transactions of Royal Society of Edinburgh*, x. 10.

compact, and friable. When distinctly crystallised in forms of the hexagonal system, having a metallic lustre, and a specific gravity of 4·8 to 5·3, it is called *specular iron*. When it assumes a micaceous structure it is called *micaceous iron*. The compact variety, having sub-metallic, or no metallic lustre, occurring in mammillary dendriform masses, and having a fibrous structure, is called *hematite*, a name which is now used as the generic name of all the varieties. The soft varieties are called *red ochre* or *eisenrahm*, or *red iron froth*, or *scaly red iron* when it consists of slightly coherent scales. It also occurs mixed with various proportions of clay, as *argillaceous iron ores*, *reddle* or *red chalk*, etc. Specular iron occurs chiefly in schistose and crystalline rocks, and is sometimes found in ejected lava. Hematite, including under this term all the varieties, occurs in veins associated with calcite, quartz, and barytes, and in beds. The softer varieties occurring in secondary rocks in the condition just mentioned, and also in nodules or lumps in shales, are the result chiefly of the decomposition of chalybite or carbonate of iron. The fibrous, and massive reniform or kidney iron ore, may be considered as the passage from the colloid hydrated to the crystallised oxide.

Two hydrates of ferric oxide are known—*Limonite* or *brown hematite*, and *göthite*. The former represents the orthic hydrate, $Fe_2(Ho)^6$, or $Fe''_2O_3 3H_2O$. It occurs in mammillary, stalactitic, and botryoidal forms, fibrous, sub-fibrous, massive, and earthy, but at most only indistinctly crystallised. The orthic hydrate should contain 25·23 per cent of water, ~~but~~, except some bog-iron ores, it rarely exceeds from 13 to 15 per cent. *Bog-iron ore* appears, like the corresponding earthy hydrated silica, to have been, in part at least, produced by the action of animals. *Yellow ochre* (*vitriol ochre*, etc.) is an argillaceous variety, containing basic ferric sulphate, silicates, arsenates, etc. Limonite occurs in secondary and recent formations, being formed by deposition from water, or oxidation of carbonate derived from denudation of calcareous and dolomitic rocks. Yellow ochre is perhaps in most cases a deposit from water containing green vitriol derived from the oxidation of pyrites.

Göthite is the meta-hydrate $Fe'''_2O_2(Ho)^2$, or Fe_2O_3,H_2O, which should contain 10·11 per cent of water. It crystallises in rhombic or trimetric prisms, and also occurs fibrous, reniform, foliated or scaly, and massive. Its colours are yellowish, reddish, and blackish-brown. There are many varieties, differing chiefly in structure, colour, and associations; thus, *rubinglimmer* is a hyacinth-red micaceous variety; *stilpnosiderite* is an amorphous stalactitic or massive kind; *needle-iron ore* is a fibrous radiated variety.

Native ferroso-ferric oxide is called *magnetite*, from the circumstance that the natural loadstone is chiefly of this ore. It occurs chiefly crystalline, the crystals being modifications of the octahedron, sometimes of the rhombic dodecahedron. Its colour is usually black. It has generally a metallic lustre. It is also found granular, compact, earthy, and as sand. It occurs both in veins and beds, associated with gneiss, syenite, clay-, chlorite-, and hornblende-slates and greenstones. It also occurs disseminated through those rocks, of which it forms an important constituent. It may be looked upon as the representative of the spinels, in which the alumina is replaced by ferric oxide—indeed, some varieties contain magnesia. The variety known as *franklinite*, in which zinc and manganese replace more or less the ferrous oxide, represents gahnite or zinc spinel.

Hematite and magnetite occur as true rocks, sometimes forming whole mountain masses, such as the Magnetberg in the Oural, and Iron Mountain and Pilot Knob in the Rocky Mountains. The two latter consist of hematite.

Perimorphs.—The following minerals inclose *specular iron*: fluor-spar, quartz, rutile, zincite, pyrites, barytes, apatite, bitter-spar, scapolite, dichroite, cancrinite, adular, albite, oligoclase, topaz, heulandite. The following minerals have been described as perimorphs of *magnetite*: quartz, bitter-spar, dolomite, apatite, augite, actinolite, garnet, idocrase, scapolite, epidote, allanite (orthite), sodalite.

nepheline, orthoclase, topaz, tourmaline, phillipsite, datholite. *Oxide of iron* has been found inclosed in: quartz, rutile, diaspore, chalybite, cerusite, smithsonite, anglesite, garnet, zircon, natrolite (bergmannite). *Iron foam* has been found inclosed in: fluor-spar, calcite, bitter-spar, barytes, analcime, chabazite, harmotome.

Endomorphs.—The following minerals have been noticed as *endomorphs*—that is, inclosed in *magnetite:* pyrites, copper pyrites, amianthus, scapolite, nepheline, talc, chlorite; in *iron-glance:* rutile, brookite.

Pseudomorphs.—The following pseudomorphs of the oxides of iron have been described:—*Hematite* in the form of: fluor-spar, quartz, magnetite, limonite, göthite, pyrites, barytes, calcite, dolomite, chalybite, pharmacosiderite or arseniate of iron, garnets. *Limonite* in the form of: fluor-spar, quartz, red copper, specular iron, pyrites, marcasite, galena, blende leucopyrite, barytes, calcite, dolomite, chalybite, ankerite, spherosiderite, cerusite, pyromorphite, pharmacosiderite scorodite, augite (pyroxene), jeffersonite, beryl, thomsonite (comptonite). *Göthite* in the form of: pyrites, barytes, calcite, dolomite, smithsonite, calamine, vivianite. *Magnetite* in the form of: specular iron, chalybite, actinolite, mica.

Pyrolusite.—Manganese is very widely diffused. Small quantities of it are present in nearly all iron ores. Although manganese minerals rarely occur in such masses as to constitute rocks, and that the metal itself does not form an important constituent of rocks, yet from the functions which it appears to perform in many decompositions, the student should be acquainted with the forms in which it naturally occurs. The most important compound of manganese is the manganic dioxide or *pyrolusite*, a black or dark steel-grey mineral, which occurs massive, granular, and reniform, with a fibrous crystalline structure. The sesquioxide of manganese Mn_2O_3 also occurs as *braunite*, and hydrated as the common ore *manganite* $Mn_2O_3H_2O$. Some specimens contain much more water, so that it probably represents limonite, with which it appears to be isomorphous. The representative of the meta-hydrate is *polianite*, which is isomorphous with göthite. There is another ore of manganese, containing a variable quantity of water, but to which no definite formula can be assigned, *psilomelan*. This mineral is probably a mixture. There is also a representative of magnetite, the manganoso-manganic oxide $Mn''Mn'''_2O_4$ or *hausmannite*.

Pyrolusite, hausmannite, and braunite occur as pseudomorphs in the form of manganite, and all four in the form of calcite.

Sulphides of Iron.—Two sulphides of iron occur in nature, ferric-disulphide FeS_2, and ferroso-ferric sulphide Fe_3S_4, or $Fe''Fe'''_2S_4$. Ferric-disulphide is dimorphic. When it crystallises in the monometric system it is called *pyrites*, and by miners *mundic;* when it crystallises in the trimetric or rhombic system it is called *marcasite*. Pyrites occurs crystallised in cubes, octahedrons, cube-octahedrons, pentagonal dodecahedrons, etc.; also in cylindroidal and globular stalactites and mammillated, the surface being covered with crystalline facettes, and the interior fibrous, compact, etc. Pyrites has a characteristic bronze to golden yellow colour, nearly uniform. Some varieties contain copper; others nickel, or cobalt, or gold, or silver. Pyrites is one of the most diffused minerals in nature. It is found disseminated in rocks of all ages. It occasionally forms veins of considerable extent, or mixed with a kind of clay thin beds. Massive pyrites, more or less pure, or mixed with clay, is used for making sulphuric acid under the name of *sulphur ore*. Pyrites is deposited by thermal-mineral waters, containing sulphuretted hydrogen and iron at the same time, such as those of Chaudes-Aigues in Cantal, and of Bourbon-Lancy in the department of Saône-et-Loire. In the throat of the sulphur springs of Bagnerres de Luchon in the Pyrenees, cubic crystals of pyrites are deposited on crystallised barytes. According to Ebelmen, pyrites is daily formed wherever organic matter in decomposition acts on the sulphates of mineral or sea water in the presence of ferruginous mud. Marcasite is of a pale bronze colour,

sometimes inclined to grey, and has hence been called *white iron pyrites.* It occurs in acicular or fibrous radiated masses, the *strahlkies* or radiated pyrites of Werner; in macled crystals, forming dendritic configurations (*spear pyrites*); in crest-like aggregations, like the comb of a cock, hence named *cockscomb pyrites.* Marcasite, when it begins to decompose, becomes externally of a liver-brown colour. The term *hepatic pyrites* or *leberkies* is given to this variety. Marcasite is not so abundant a mineral as pyrites: it is not found, for instance, in beds or deposits in old slate rocks, but it occurs in the mineral veins which traverse those rocks. It is more or less disseminated in the carboniferous formation, and appears to become more frequent the newer the rock. It is disseminated often in such a fine state of division as to be imperceptible in bituminous shales, coal shales, etc. In the shales and clays of the lias and cretaceous periods, as well as in some coals of the carboniferous period, it occurs in the form of balls and irregular masses of more or less considerable size. It also occurs in radiated globular masses and beautiful spear macles in the white chalk itself. *Arsenical pyrites* or *mispickel,* which contains arsenic as well as sulphur, although differing several degrees in its angles from marcasite, is perhaps homœomorphous with the latter. Ferroso-ferric sulphide constitutes the mineral *pyrrhotine* or magnetic pyrites, which crystallises in forms of the hexagonal system. Its true colour is between bronze-yellow and copper-red, but owing to the facility with which it tarnishes it is usually of a reddish-brown colour. It is softer than common pyrites. It usually occurs massive in fissures in crystalline rocks with magnetite, and rarely in crystallised plates. Perfect crystals are very rare. Its name, magnetic pyrites, is due to its weak magnetic properties.

The three sulphides of iron, when exposed to damp air, oxidise, and produce ferrous sulphate or green vitriol. Perfectly pure cubic pyrites is, however, acted upon very slowly, and it is therefore probable that the varieties of that mineral which decompose readily are mixed with marcasite, which is sometimes found not only associated with pyrites but penetrating it. Marcasite oxidises so readily that it is very difficult to preserve specimens of it, especially casts of fossils composed of it. Next to water and carbonic acid there is no substance performs so important a function in nature as an agent of metamorphosis as sulphide of iron. During its oxidation a considerable quantity of free sulphuric acid is formed, which, acting on neighbouring minerals, among others on aluminous silicates, dissolves considerable quantities of matter, including a very considerable quantity of the latter. This solution, when it circulates in fissures and penetrates rocks, is a powerful agent of change. Of the quantity of aluminous silicates dissolved in a nascent state in water containing free sulphuric acid thus formed, an idea may be formed from the fact that the water pumped up from one mine in Ireland annually carries away more than one hundred tons of silicate of alumina.

Pseudomorphs.—Substances which decompose so readily and rapidly, with evolution of heat, increase of bulk, and the production of soluble substances which act upon surrounding bodies, do not offer favourable conditions for the production of pseudomorphs. The following minerals are found in the form of *Pyrites*:—graphite, quartz, hæmatite, göthite, limonite, marcasite, pyrohotine, copperas. Pyrites is found in the forms of the following minerals:—quartz, specular iron, marcasite, mispickel, pyrohotine, galena, stephanite or brittle silver, polybasite, pyrargyrite or ruby-silver, barytes, anhydrite, calcite. Stephanite and calcite have been observed in the form of *marcasite.* Pyrites has been found in the forms of *pyrohotine* and *mispickel.*

Perimorphs.—Pyrites has been observed enclosed in the following minerals:—diamond, gold; fluor-spar; quartz, magnetite; pyrites, pyrohotine, galena; barytes, gypsum, coelestine; boracite, calcite, bitter-spar, diallogite; augite, malacolite, actinolite, beryl; garnet; scapolite, dipyre, dichroite or iolite, fahlunite or hydrous iolite; lapis lazuli, adularia, felspar; apophyllite; harmotome, stilbite, datholite; scheelite.

Marcasite or radiated pyrites has been observed in the following minerals :—gold, fluor-spar, quartz, pyrites, pyrargyrite or ruby-silver ; barytes ; calcite, magnesite, chalybite ; apophyllite ; apatite.

Pyrohotine has been observed in quartz ; pyrites ; calcite ; hornblende, scapolite (wernerite), dichroite or iolite, apophyllite.

Endomorphs.—The following minerals have been found in pyrites :—carbon, gold ; fluor-spar ; quartz, specular iron ; marcasite, pyrohotine, galena, realgar ; gypsum ; calcite ; pyrope-garnet, zircon, mica, felspar, staurotide.

Sulphates.—The sulphates of geological importance are : thenardite, glauber salt, glauberite, gypsum, anhydrite, barytes, and alunite.

Sulphate of soda, although not occurring as a rock except in one instance, or forming a constituent of rocks, is found under so many circumstances that it has great interest for the geologist. It exists in the waters of many saline hot springs, and especially in that of Carlsbad ; it is formed in winter in salt lakes containing sulphate of magnesia. It sometimes crystallises out mixed with the latter as a particular mineral called *astrakanite*, $Na'_2Mg''2SO_4,4H_2O$, in some of the salt lakes about the mouths of the Volga. In the region of Lake Aral are several lakes, the waters of which hold it in solution, and from which it crystallises. Many beds of clay in this region also abound in it. In many of the great salt deposits it occurs in small quantity. It effloresces at certain seasons on the surface of the soil in many places, notably at Bahia Blanca, in South America, which derives its name from the circumstance. The only recorded instance where sulphate of soda forms a true rock is in the valley of the Jarama, a tributary of the Tagus, in the centre of Spain.* It occurs there as anhydrous sulphate or *thenardite*, Na_2SO_4, and as *glauberite*, a compound of the anhydrous sulphates of calcium and of sodium, $Ca''Na_22SO_4$, associated with clay and gypsum in beds extending for several miles, and which in some places are from fifty to sixty feet thick. It was in this district, at Espartinas, that thenardite was first discovered ; but until the discovery of these beds it was a very rare mineral, only found at the place just mentioned, and at Tarapaca in Peru, where it is also associated with glauberite. The latter, except in the valley of the Jarama, is also a rare mineral occurring in small quantity in great salt deposits. Thenardite and glauberite, on exposure to the air, absorb water, and, when acted upon by water, dissolve—the former entirely and the latter in part. A deposit of glauber salt, $Na'_2SO_410H_2O$, has accordingly formed along the escarpment of the beds.

Calcic sulphate or sulphate of lime occurs in nature hydrated as *gypsum*, and anhydrous as *anhydrite*. The latter is found in connection with common salt, the form of which it often imitates, the salt in turn being found as a pseudomorph of the anhydrite. Anhydrite is harder than gypsum, with which it is generally associated. It occurs in crystals of the trimetric or rhombic system, but more usually in lamellar, saccharoidal, and compact masses. The variety known as *vulpanite*, found at Vulpino, in the north of Italy, contains about 8 per cent of silica. Its specific gravity is from 2·889 to 2·957, and its hardness 3·5, or about that of calcite. It is used as a marble under the name of bardiglio di Bergamo. In Nova Scotia anhydrite forms extensive beds belonging to the carboniferous period.

Gypsum, or hydrated calcic sulphate, $Ca''SO_4,2H_2O$, crystallises usually in monoclinic prisms ; it also occurs laminar, lamellar, fibrous, bacillary, saccharoidal, and compact, mixed with calcic carbonate or carbonate of lime, clay, and sulphur of various colours, but usually white. The transparent crystals are called

* "On the Deposit of Sulphate of Soda in the Valley of the Jarama, near Aranjurez, in Spain," by William K. Sullivan and J. P. O'Reilly, *Atlantis*, vol. iv. p. 228 ; and "Notes on the Geology and Mineralogy of the Spanish Provinces of Santander and Madrid," by the same authors ; London, 1863.

selenite, the fine fibrous variety *satin-spar*, and the saccharoidal and compact varieties *alabaster*. Gypsum occurs in all formations, from the upper silurian to the most recent, especially in the carboniferous, permian, and miocene. It is found even in crystalline rocks. It is deposited during the evaporation of brine, and is produced by the action of sulphuric acid generated by the oxidation of sulphur or pyrites, or evolved from volcanic fissures. The quantity of sulphuric acid sometimes found in volcanic districts is well illustrated by the hot springs of the volcanic region of New Granada, in South America ; two of these produce actual rivers of warm acid water. One of them, first described by A. von Humboldt, has received the expressive name of Rio Vinagre or Vinegar River. Gypsum is a very soft mineral, its hardness being only 1·5 to 2·0, or not much more than half that of anhydrite ; its density is also less than that of that mineral.

Perimorphs.—Anhydrite has been observed as an enclosed mineral in quartz and rock-salt ; and gypsum in rock-salt, pyrites, and gypsum. *Endomorphs.*—The following minerals have been observed enclosed in gypsum :—sulphur, coal, brown coal, gold, quartz, limonite, pyrites, marcasite, chalcopyrites, cinnabar, realgar, antimony glance, stephanite or brittle-silver ore, gypsum, calcite, bitter-spar, azurite, malachite, amianthus, asbestus, pyrope, dioptase, humboldtite (datholite). *Pseudomorphs.*—Anhydrite occurs in the form of common salt, pyrites, gypsum, and calcite. Gypsum occurs in the form of common salt, anhydrite, and calcite ; quartz, limonite, calcite, and strontianite in the form of gypsum ; and calcite, dolomite, and common salt in the form of anhydrite.

BARYTES, baric sulphate, or sulphate of barium $Ba''SO_4$, crystallises in the rhombic or trimetric system. Its hardness is 2·5 to 3·5, or the same as that of calcite. Its specific gravity is from 4·38 to 4·72, hence the name of heavy-spar given to it. There are also fibrous, lamellar, crested, globular, coarsely laminated, granular, and massive varieties. When pure it is white, and the crystals transparent, but it is often yellowish-grey, blue, red, or brown, and opaque. Barytes is a frequent mineral in metallic veins ; it also occurs as distinct veins, especially in limestones, sometimes accompanied by sulphate of strontium or celestine and calcite. Crystals of it are found in the hot sulphurous springs of Bagnerres de Luchon. Its chief geological interest lies in its connection with mineral veins, hot springs, and pseudomorphism.

Endomorphs.—The following minerals have been noticed in crystals of barytes : —bismuth, mercury, silver ; fluor-spar ; quartz, micaceous iron, red iron foam, manganite, göthite (pyrohosiderite), limonite ; orpiment, realgar, stibnite, bismuthine, silver glance, galena, blende, cinnabar, pyrites, marcasite, smaltine, chalcopyrite, heteromorphite, bournonite ; barytes—the internal crystal of barytes being sometimes separated from the external shell of the same mineral by pyrites. Dolomite crystals have also been observed on one side of the internal crystal—breunnerite (bitter-spar). Cavities have also been noticed in crystals of barytes. Sometimes the cavities are full of liquid, sometimes only partially filled. Professor Nicol has noticed that the liquid in the former case yielded crystals of barytes when exposed to the air. In partially-filled cavities the liquid has been found to disappear at about 150° Cent., so that the liquid must have been very volatile. *Perimorphs.*—Barytes has been observed enclosed in fluor-spar, quartz, and calcite. *Pseudomorphs.*—Barytes in the form of: dolomite, calcite, witherite, baryto-calcite. Minerals in the form of barytes : quartz, red iron ore, limonite, göthite, psilomelane ; pyrites ; calcite, dolomite, chalybite, cerussite ; steatite.

ALUNITE or ALUM-STONE is a basic sulphate of aluminium and potassium, formed by the decomposition of trachyte by sulphurous acid vapours. It occurs chiefly massive, of a greyish-white or reddish colour, from intermixed ferric oxide. The cavities of the massive mineral are sometimes lined with small crystals, the composition of which might be represented by the formula $K''_2Al'''_2(SO_4)^4$, $3(Al_2O_3.3H_2O)$, or a mixture of that salt with one having the composition $K_2Al'''_2(SO_4)^4$

$2(Al_2O_3.3H_2O)$. Some varieties contain less water than even the latter formula would require. The massive varieties contain sometimes as much as 60 per cent of intermixed silica. At Tolfa, near Civita Vecchia, the alunite forms thick layers on trachyte, which being differently coloured, owing to the different states of oxidation of intermixed iron, have a ribboned appearance when cut across. This mineral is so hard that it can be polished so as to form a fine marble. In Hungary it is so hard as to be used for millstones. The formation of the alunite is accompanied by the production of large quantities of silica, some of which, as just stated, remains intermixed with the alunite, but the principal part forms quartz veins, sometimes honey-coloured, or of the colour of eisenkiesel from intermixed ferric oxide.

The production of alunite is not to be confounded with the formation of alum from ordinary alum-slate. This is a bituminous slate containing disseminated sulphuret of iron. When exposed to the air, the latter oxidises, and the slate swells up, from the formation of salts between the layers.

Carbonates.—The carbonates of the bivalent metals may be classified into two categories according to their crystalline forms, namely, hexagonal and rhombic carbonates. Calcic carbonate, or carbonate of lime, crystallises in forms belonging to both systems, or, in other words, it is dimorphic. The hexagonal forms are included under the term *calcite*, the rhombic under that of *aragonite*. All the other carbonates are homœomorphous with one or the other of these. The calcite group includes the carbonates of magnesium, iron, manganese, and zinc; the aragonite group the carbonates of strontium, barium, and lead. Of these carbonates the only ones which enter into the composition of rocks are the carbonates of calcium, magnesium, and iron.

CALCITE or CALC-SPAR is, next to quartz, the most abundant mineral in nature. Clear colourless masses, cleaving readily into rhombohedrons, are found in Iceland, hence the name of *Iceland spar* given to such cleaved pieces possessing well-marked double refraction. Zippe has described in a monograph on the subject forty-two different rhombohedrons, eighty-five sclenahedrons, and seven dihexahedrons of calcite. The mutual combination of these simple forms, to which must be added hexahedral and trihedral prisms, gives rise to a multiplicity of modified forms, of which De Bournon has described about 700. Calcite is very often mixed with other isomorphous carbonates, $Mg''CO_3$, $Fe''CO_3$, $Mn''CO_3$, $Zn''CO_3$, in the most variable proportions. A specimen from Altenberg or Vieille Montagne, for example, was found to contain 89·56 per cent of $Ca''CO_3$, 8·23 of $Fe''CO_3$, 0·69 of $Mn''CO_3$, and 1·01 of $Zn''CO_3$. Some of those mixtures get special names; thus when the mineral contains an equal number of molecules of the carbonates of lime and magnesia, it is called *dolomite*.

Pure calcite has a specific gravity of 2·69 to 2·75, and its hardness is 3 in the scale of Mohs, which has ten degrees, commencing with talc and ending with the diamond. True dolomite, $Ca''CO_3$, $Mg''CO_3$, which would consist of 54·3 per cent of $CaCO_3$ and 45·7 per cent of $MgCO_3$, is much denser and harder than calcite; its density varies from 2·88 to 2·95, and its hardness from 3·5 to 4·5. It is also much more slowly acted upon by solvents. Specimens of the composition represented by the formulæ $3CaCO_3$, $2MgCO_3$; $2CaCO_3$, $MgCO_3$, etc., are also often met with. The composition of many specimens, especially of the compact varieties, cannot be expressed by formulæ. The angle of the type or fundamental rhombohedron of dolomite is 106° 15′, or a mean between that of pure calcite 105° 5′, and of magnesite or bitter-spar $Mg''CO_3$, which is 107° 25′.

Carbonate of calcium forms a similar compound with carbonate of iron, called *ankerite*, which may be represented by $Ca''CO_3$, $Fe''CO_3$; but it is perhaps never of this composition, for it always contains some of the other carbonates, such as, $MgCO_3$ and $MnCO_3$. *Plumbo-calcite* and *Baryto-calcite* are calcites containing carbonate of lead and carbonate of barium respectively.

ARAGONITE is denser than calcite, although the latter is the more stable form; it

is in this respect an exception to the rule that the most stable form of dimorphic bodies has a higher density than the less stable. Its density varies from 2·920 to 2·960; when powdered it is from 2·50 to 2·51. It is also harder than calcite, its hardness being from 3·5 to 4. Like the rhombohedral carbonates, the rhombic carbonates mix with each other in the formation of crystals. Thus many aragonites contain $Sr''CO_3$, which by itself constitutes the homœomorphic mineral *strontianite;* $BaCO_3$, which crystallises alone as *witherite*, and is also homœomorphic with aragonite, forms with carbonate of calcium the mineral *alstonite*. This mineral consists of $BaCO_3$, $CaCO_3$, and a variable quantity of $SrCO_3$. This is also the composition of baryto-calcite, so that carbonate of barium is likewise dimorphic, its most stable form being, however, rhombic. When the corresponding forms of two dimorphic bodies are similar, the bodies are said to be isodimorphic; the carbonates of calcium and barium are therefore isodimorphic. Carbonate of lead is also dimorphic, and isodimorphic with calcic carbonate, as is shown by its crystallising with calcite in plumbo-calcite, and with aragonite in *tarnowitzite*, a specimen of which contained 3·86 of plumbic carbonate.

When large crystals of aragonite are heated, they sometimes swell up suddenly and fall to pieces; smaller pieces and the fibrous varieties become rotten. Occasionally bacillary and radiated masses of aragonite appear to slowly acquire the molecular structure of calcite, a change which is indicated by the cleavage. Such paramorphic crystalline masses are found in volcanic districts.

The causes which determine calcic carbonate to crystallise by preference in forms of one, rather than that of the other system, are not known. It is generally assumed that aragonite is formed from hot solutions, and calcite from cold solutions. Aragonite is, however, frequently formed from waters at ordinary temperatures. It is probable that the crystallisation of aragonite is dependent in nature upon the presence of excess of alkaline carbonates, while calcite is formed in water containing little or no alkaline carbonates. This view seems to be borne out by an observation of Becquerel, that when gypsum is immersed at ordinary temperatures in a strong solution of monosodic carbonate (bicarbonate of soda), calcic carbonate is deposited as aragonite, but in dilute solutions as calcite.

Besides the numerous crystalline forms of *calc-spar*, calcite occurs saccharoidal as crystalline limestone, which when perfectly white is *statuary marble*. The term *marble* is also given to a number of imperfectly crystalline varieties, which admit of a high polish, and which are variously coloured by carbon, ferric oxide, etc. Many limestones contain a considerable amount of clay intermixed through them. In some of those earthy limestones the clay is able to combine with the lime when it is burnt; such limestones are called *hydraulic limestones*. The *stalactites*, which depend from the roofs of caverns, and the *stalagmites*, or irregular masses of calcic carbonate which form on the floors of caverns, are deposited from the water oozing through the roof. When the carbonate precipitated from water is white, loose, and friable, it is *agaric mineral*, or generally *calc sinter;* when coherent and sufficiently hard not to be friable, it is *calcareous tufa*. When stalactitic calcite is hard, semi-translucent, yellowish-white, or somewhat opalescent, it forms the true *alabaster*. When calcite occurs in small spherical grains, cemented together like the roe of fish, it is called *oolite*. When the grains are larger, about the size of a pea, it is termed *pisolite*. *Marl* is a friable earthy variety of calcite, containing a variable proportion of clay.

Carbonate of Magnesium as a separate mineral, Magnesite, is of very secondary importance to the geologist. It occurs chiefly associated with serpentine. Combined with calcic carbonate it forms the mineral *dolomite* or *bitter-spar* already mentioned, and the immense masses of dolomitic limestones which occur especially among the jurassic rocks. Combined with carbonate of iron it forms the mineral *breunnerite* or *mesitine spar* $MgCO_3, FeCO_3$. This formula represents 42 per cent of carbonate of magnesium, and 58 per cent of carbonate of iron. But the pro-

portion varies very much, some specimens containing so little as to be reckoned as impure magnesite. All dolomitic rocks contain some ferrous carbonate, but sometimes the quantity equals or even exceeds the amount of magnesic carbonate. These varieties of dolomite are included under the name of *ankerite* with those containing very little magnesic carbonate. The name *brown spar* is sometimes given to dolomites and some kinds of breunnerite, which in consequence of the considerable amount of ferrous and manganous carbonates which they contain become brown and even black by oxidation, hence the name brown spar. The ferrous carbonate of dolomitic limestones, which often amounts to 4 or 5 per cent, and sometimes to very much more, is the source in many cases of great deposits of carbonate of iron, and of hematite and limonite, when the dolomite is denuded.

CHALYBITE or SPATHIC IRON is the name given to ferrous carbonate when found crystallised or massive. Like the other carbonates mentioned it is generally mixed with more or less carbonates of manganese, magnesium, calcium, and zinc, especially with the two first. One of those mixtures containing $2MnCO_3,3FeCO_3$ is called *oligon spar*. Chalybite occurs in the older rocks and associated with limestones in veins and in beds, which are sometimes of enormous extent. Mixed with clay, and as in Westphalia with coal and clay, ferrous carbonate forms the important ore of iron, *clay-ironstone*, which occurs so abundantly in many parts of the coal-measures, and in the lias and oolite of England.

The carbonates of calcium, magnesium, manganese, iron, zinc, etc., are soluble to some extent in water saturated with carbonic acid. If the water be saturated with the gas, under a considerable pressure and at a high temperature, their solubility becomes greatly increased. Hence many thermal waters contain so much calcic carbonate that they deposit large quantities when they come to the surface. When water containing carbonates of calcium, magnesium, iron, and manganese, is exposed to the air, the manganic carbonate is converted into manganite or hydrous manganic oxide, or into pyrolusite or manganic dioxide, which is precipitated first, the ferrous carbonate gradually oxidises, and is precipitated as ferric hydrate. The carbonate of calcium then crystallises out mixed with carbonate of magnesium, if it separates as calcite, but almost free from it if it separates as aragonite. The calcic carbonate that separates last is free from iron. In this way we can understand why the *flos ferri* or *flower of iron*, a coralloidal form of aragonite, which is found in beds of iron ore, is so free from iron. When the carbonates precipitate without access of oxygen, this separation does not take place, at least to the same extent.

There can be no doubt that true dolomite may be formed by precipitation from sea-water. It is, however, also formed by metamorphic action. The process of dolomitisation may sometimes be followed through all the stages in blue limestone, which becomes brownish-yellow as the metamorphosis advances. That colour is due to the iron which is introduced along with the magnesia, often to the extent of 3 or 4 per cent; veins of breunnerite being sometimes even formed.

Endomorphs or minerals enclosed in *calcite* crystals: silver, mercury, copper, gold; fluor-spar; quartz, rutile, brookite, specular iron, iron froth; realgar, antimony glance or stibnite, silver glance, erubescite, galena, cinnabar, millerite, pyrohotine, pyrites, marcasite, mispickel, breithauptite or antimonial nickel, chalcopyrite, plagionite, pyrargyrite or ruby-silver, tetrahedrite; barytes, celestine; chalybite, smithsonite, azurite, malachite; amianthus, green earth, garnet, idocrase, epidote, mica, titanite, glauconite (hislopite), metachlorite, apophyllite, calamine, mesotype, stilbite (desmine); apatite.

Endomorphs in *aragonite:* quartz; barytes; calcite, aragonite, strontianite; mica. Sorby observed cavities in aragonite in Vesuvian lava containing a liquid and air; the latter occupied about one-tenth of the space of the fluid, whence he concludes that the cavities were formed at a temperature of about 160° Cent.

Endomorphs in *dolomite:* mercury; specular iron, iron froth, magnetite;

silver glance, cinnabar, pyrites, chalcopyrite; amianthus, albite talc; cobalt bloom.

Endomorphs in *breunnerite:* talc. *Endomorphs* in *chalybite:* bismuth; quartz, rutile, oxide of iron; galena, pyrites, chalcopyrite, marcasite, bismuthine, gersdorffite (tombazite); mica.

Perimorphs or minerals enclosing *calcite:* sulphur; quartz, pleonaste or iron and magnesia spinel; galena, pyrites, gypsum, anglesite; calcite, aragonite; hornblende, garnet, zircon, idocrase, scapolite, felspar, loganite (pyrosclerite); apatite.

Perimorphs of *aragonite:* aragonite. *Perimorphs* of *dolomite:* fluor-spar; quartz; barytes, gypsum; calcite, dolomite. *Perimorphs* of *breunnerite:* quartz, olivine.

Pseudomorphs.—In the form of *calcite:* fluor-spar; quartz, carnelian chalcedony, hornstone, semi-opal, hematite, limonite, göthite, stilpnosiderite, manganite, pyrolusite, hausmannite, minium, psilomelane, wad; blende, galena, pyrites, marcasite; barytes, gypsum; calcite, dolomite, chalybite, diallogite, smithsonite, malachite; orthoclase, steatite, meerschaum, chlorite, calamine. In the form of *dolomite:* common salt, quartz, chalcedony, hematite, göthite, limonite, manganite, hausmannite, psilomelane, pyrolusite; pyrites, marcasite; barytes; chalybite, diallogite, azurite; steatite, serpentine, calamine. In the form of *chalybite:* quartz, magnetite, hematite, limonite, chlorite.

Calcite in the form of: fluor-spar; gypsum, anhydrite; gay-lussite; pectolite. *Dolomite* in the form of: fluor-spar; anhydrite, barytes; calcite. *Chalybite* in the form of: barytes; calcite, dolomite.

Silicates.—The silicates form not only the most numerous, but, to the geologist, by far the most important family of minerals. Although many of the rarer silicates occurring as endomorphs, perimorphs, or pseudomorphs, throw great light on the genesis and metamorphosis of rock masses, the number, a knowledge of which is absolutely indispensable to the student in order to study lithology, is comparatively small. These belong chiefly to the augite, olivin, and felspar groups —which may be considered the primitive mineral constituents of crystalline rocks; the garnet or epidote, mica, leucite, nepheline, haüyne, talc, serpentine, chlorite, pectolite, and zeolite groups, as their intermediate and secondary constituents.

AUGITE GROUP: This group includes two principal sub-groups, augite or pyroxene and its varieties, and hornblende and its varieties.

PYROXENE or AUGITE includes a number of minerals belonging to the same crystalline series, and possessing more or less identity of physical structure with considerable varieties of chemical composition and colour. The crystals belong to the monoclinic system, the inclination of the inclined axes being 74°, and the angle of the type prism 87° 6′, parallel to which it cleaves. The specific gravity varies from 3·23 to 3·50; the hardness lies between 5 and 6. The colours are white, various shades of green, brown, and black. The lustre vitreous inclining to resinous, sometimes pearly. Generally translucent to opaque, rarely transparent. The density, hardness, lustre, colour, and transparency, vary with the relative proportion of the metals, calcium, magnesium, iron, and manganese, which the varieties contain. Chemically the augites may be classified into non-aluminous and aluminous augites. The former consist of meta-silicates of calcium, magnesium, iron, and manganese, and the latter of those silicates with an aluminous silicate. The simplest typical formula for augite would be $Ca''Mg''2SiO_3$, or a calcic magnesic disilicate, which represents the composition of *diopside* or *white augite.* The crystals of diopside are, however, usually greenish, indicating the presence of meta-silicate of iron. *Sahlite, pyroxene,* in a limited sense, *malacolite, fassaite,* white and green *coccolite, hedenbergite,* etc., are varieties of the non-aluminous augites.

The aluminous augites contain, according to Tschermak, besides the normal augitic meta-silicates, the silicate $MgO,Al_2O_3SiO_2$. Such a silicate may no doubt exist in some aluminous augites, but in the majority of them the alumina is derived

from the felspar in which the crystals were formed. Sometimes the alumina and magnesia are present in part as $Mg''Al'''_2O_4$, a compound represented by spinel, or as $[Mg'',Fe'']''Al_2'''O_4$, or a magnesia-iron spinel. The perimorphs and endomorphs of augite show that the aluminous silicate varies with the conditions under which the crystals were formed. The aluminous silicates are allomorphs taken up by the augitic meta-silicates; and their amount depends upon the relative proportion, among other things, of the substances forming the fluid mass from which the crystals separate. The common augites are chiefly black, and greenish and brownish-black and very lustrous, hence the name, from αὐγή, lustre. The crystals cleave like hornblende parallel to the faces of the monoclinic prism. In the augites of both classes the magnesium is sometimes almost wholly replaced by calcium and iron. The hedenbergite above mentioned is an example of the non-aluminous, and its American variety, hudsonite, of the aluminous varieties. Hudsonite is extremely ferruginous, and contains about 10 per cent of alumina, partly, no doubt, as felspar, and partly, perhaps, as an iron spinel like hercinite.

There are several other minerals which may be regarded as varieties of augite, such as some of the specimens of the calcic sodic disilicate, *ægyrin* (others are referred to the hornblende sub-group); *acmite*, which contains alumina, a zinc augite called *jeffersonite*, and a nearly pure meta-silicate of manganese called *rhodonite*, from its rose-red colour.

Enstatite, which may be represented by the general formula of augite, is a silicate of magnesium, sometimes, however, combined with silicate of iron $Fe''SiO_3$. Descloizeaux has, however, shown that it is rhombic, and not monoclinic, the obtuse angle of its prism being 92° to 93°, cleaving parallel to faces of the prism, the face of cleavage having a fibrous aspect. Its colours are light grey, yellowish or greenish. It forms a constituent of some rocks, as, for instance, lherzolite, a Pyrrenean rock consisting of olivine, diopside, and this mineral.

Augites exhibit a tendency to take up water. Scheerer suggested that this water replaced magnesia, three molecules of water replacing, according to his hypothesis of *polymeric isomorphism*, one of magnesia. It is more probable, however, that it represents the water of the orthic acid, or the saturated condensed acid corresponding to the original augite. When augites take up water in this way they may be regarded as in the first stage of alteration. The most important of these hydrated augites are diallage and bronzite. *Diallage*, which includes *Schiller spar* in part, is a thin foliated mineral, cleaving readily in a direction parallel to the orthic or rectangular secondary axis, the cleavage parallel to the prismatic face being unrecognisable. Some varieties have a kind of striated surface, which produces a dull mother-of-pearl lustre. Its colour is of various shades of pale green, greyish-green, grey and brown, and sometimes bronze. When of the latter colour, it may be considered as *bronzite*. Diallage is, however, generally more calcareous than bronzite, in which the magnesia generally predominates. The latter has a laminar structure, well marked in some varieties, but inclined to a fibrous structure in others. Diallage may be regarded as the hydrous representative of the calcareous augites, and bronzite of the magnesian. Both are related to the mineral *hypersthene*. This mineral derives its name from ὑπέρ σθένος, over strength, because it is denser and harder than hornblende. It is a highly ferruginous, slightly hydrated mineral, generally of a brown colour, often blackish-brown to pitch-black. Its principal cleavage face exhibits a copper red metallic iridescence, due to microscopical laminæ of titaniferous iron. According to Descloizeaux hypersthene does not belong to the augite series, with which it has hitherto been connected. He has shown that it is not monoclinic, but rhombic, the angle of its prism being 90° 30′; it cleaves like diallage, but the augitic cleavages, that is those parallel to the faces of the prism, are still distinguishable. It is harder than diallage; its specific gravity is from 3·3 to 3·4. Diallage occurs

chiefly in a kind of rock allied to serpentine, called gabbro. Bronzite occurs in serpentine, and hypersthene chiefly in a particular kind of rock called hypersthenite. There are several varieties of the preceding hydrated minerals, such as *diaclasate*, which is intermediate between bronzite and hypersthene. *Paulite* is a hypersthene from the island of St. Paul.

Bastite is a mineral of a leek to olive green, passing into yellow and brown colours, found in serpentine at the Basté, in the Hartz. It is by some considered as a slightly altered crystalline serpentine, but it is rather a variety of augite, related to bronzite and hypersthene. If its water be regarded as basic, it would be an ortho-silicate, and supports the view that the hydrated augites are meta-silicates passing into orthic silicates. Augites like hornblende assume a fibrous or asbestiform structure; these asbestiform varieties of augite represent chiefly diopside.

HORNBLENDE, like augite, is a term which includes a great variety of minerals, belonging, probably, to one crystalline series. This series belongs to the monoclinic system; the hardness varies between 5 and 6, the specific gravity between 2·9 and 3·4. The name is derived from the peculiar polished horn-like lustre of the faces of cleavage. The colours vary from black to white, through various shades of green; many tremolites are white, actinolite is of various shades of green to blackish-green, common hornblende is black, usually opaque and translucent, but sometimes, though rarely, almost transparent. The crystalline groupings and configurations are: columnar, baccillary, fibrous, parallel or radiated, rarely lamellar; granular, both coarse and fine. The fibres are sometimes so fine that the filaments may be spun.

Like the augites, the hornblendes may be divided into the non-aluminous and aluminous. To the former belong *tremolite* or *grammatite*, *actinolite*, *asbestus*, *anthophyllite*, and *cummingtonite*; to the latter *common hornblende*, *uralite*, and *diastatite*.

The hornblendes are also meta-silicates, and, like the augites, may be represented by the general formula $(M''SiO_3)^n$, in which M'' represents the metals calcium, magnesium, iron, and sometimes manganese. Augite and hornblende may be considered as dimorphic forms of the isomorphic meta-silicates just stated. The intimate relation existing between them has long been recognised. Berthier, and after him Mitscherlich, found that the fused tremolite of St. Gothard assumed the form and structure of augite on cooling, while on the other hand diopside melted in a crucible reassumed its augitic form on cooling. Gustav Rose confirmed these results by melting actinolite of zillerthal, and allowing it to cool slowly. When cold it formed a mass of radiated needles of the form of augite. It is, however, believed that the hornblende form is the result of slow cooling, and the augite form of rapid cooling. Whether this be so or not, or whether hornblende can be formed by fusion at all, it is remarkable that in almost every instance hornblende crystallises in rocks containing excess of quartz or highly-silicated minerals like orthoclase, and augite always in basic rocks, such as those containing the lime felspars. The silicates of the magnesian series—calcium, magnesium, iron manganese—appear to be polymorphic, if we recognise enstatite as a distinct species. The synthesis of augite was made by Berthier by fusing the necessary proportions of lime, magnesia, and silica in a porcelain furnace, and allowing the compound to cool slow. Augite crystals frequently occur among slags of blast-furnaces, as was first observed by Nöggerath.

The great facility with which the minerals of both series vary in composition, and in this respect they vary more than other series, is explained by the fact that the homologous, or condensed series of meta-silicic acids are polymeric, or simple multiples of H_2SiO_3 (see table of silicic acids, p. 58). Hence the union of a number of isomorphic meta-silicates is only like the union of a number of molecules of the same body, while the condensation of any of the other acids produces

a differently-constituted molecule by each successive condensation; thus $H_{12}Si_6O_{18}$ is merely six times H_2SiO_3, but $H_8Si_6O_{16}$ is not a multiple of any simpler acid. Hence a specimen of augite or hornblende may vary from $M''_2(SiO_3)^2$ to $M''_{70}(SiO_3)^{70}$, or even more, without changing the crystallographic series of the mineral, or even producing any appreciable change in the values of the angles. But $K'_2Al'''^2Si_6O_{16}$, or the formula of potash felspar, which represents the acid $H_8Si_6O_{16}$, if doubled, would represent an acid $H_{16}Si_{12}O_{32}$, belonging to a different series of homologous acids, and the hex-silicic acid of which would be $H_4Si_6O_{14}$, while the dodecasilicic acid homologous with the felspar type would be $H_{20}Si_{12}O_{34}$. These two acids would give salts wholly unlike, which could not combine in the same crystal as isomorphic molecules, though they might possibly do so to form heteromeric crystals, with different values of the angles. From this it is evident that augites and hornblendes vary in composition in a totally different way from the felspars.

Tschermak looks upon the typical formula of tremolite as $Ca''Mg''_3(SiO_3)^4$, that of augite being $Ca''Mg''(SiO_3)^2$, and believes that in the aluminous hornblendes there are in addition small quantities of two other silicates, $Ca''Mg''[Al'''_2]_2Si_2O_{12}$ or $CaO,MgO(Al_2O_3)_2(SiO_2)^2$, and $Na'_2Al'''_2Si_4O_{12}$ or $Na_2OAl_2O_3(SiO_2)^4$. Most, if not all the aluminous hornblendes, like the aluminous augites, contain felspar, and sometimes aluminates, like spinel. As the aluminous varieties of both minerals are found in felspar rocks, and have consequently crystallised in a fluid—whether fused rock or aqueous solution—containing felspar, it seems more reasonable to assume that a little of that compound is mixed up with the polymeric meta-silicates than that a totally different silicate should be formed during the crystallisation, and one, too, which does not appear to exist as an individual mineral. The microscopic examination of the crystals also supports this view.

Of the varieties of hornblende, the following are deserving of special attention:—

a. Non-Aluminous.—*Tremolite*, from the valley of Tremola, in Switzerland, $Ca''Mg''_3Si_4O_{12}$ or $Ca''SiO_3 3MgSiO_3$, is generally white, or with a greyish-greenish, or yellowish tinge. Specific gravity 2·93, transparent or translucent in single crystals, which are fibres or slender blades, distinct or traversing a gangue, or aggregated in columnar or radiated masses. It is found in granular limestone. *Calamite* (from *κάλαμος*, a reed) is an asparagus-green variety found in prismatic crystals in serpentine.

Raphilite (from *ῥαφίς*, a needle) is an asbestiform variety.

Actinolite (from *ἀκτίν*, a ray) occurs in bright-bladed, baccillary, or radiated crystals. When the crystals are distinct it is *glassy actinolite*. The crystals have a specific gravity of 3·02 to 3·05, and break transversely with facility. Under the name of actinolite are included the hornblendes, consisting of mixtures of the isomorphous meta-silicates of calcium, magnesium, and iron (ferrosum).

Anthophyllite (from *ἀνθοφυλλον*, a clove, on account of its brown colour) includes chiefly hornblendes, consisting of meta-silicates of magnesium and iron (ferrosum), white and light-coloured varieties of *asbestus* (*ἄσβεστος*, unconsumable), are usually tremolite or actinolite, and dark-coloured ones anthophyllite.

β. Aluminous.—*Common hornblende* includes the dark-green and black aluminous varieties occurring in distinct crystals, crystalline aggregates, or massive. Specific gravity, 3·1 to 3·4.

Uralite is a kind of paramorphic augite; that is, a mineral having the external form of augite and the cleavage of hornblende. The two varieties are differently mingled in different specimens. The variety of diallage of a grass to an emerald green colour, called from the latter colour *smaragdite*, which occurs as a constituent of the rock called gabbro or diallage rock, and the comparatively rare rock eklogite, has been shown to be an intergrowth of augite and hornblende.

Diastatite and *pargasite* are only varieties of common hornblende; the former

exhibiting a difference in the value of the angles, due perhaps to the quantity of magnesic aluminate which it contains.

Perimorphs.—Augite sub-group: Crystals of *augite* in—quartz, augite, hornblende, idocrase, meionite, wernerite (scapolite), mellilite, mica, sodalite, haüyne, leucite, nepheline, sanidin, titanite, analcime, thomsonite; of *diopside*—in garnet, idocrase, orthoclase; of *omphacite* in epidote; of *diallage* in hornblende; of *hypersthene* in hornblende. Hornblende sub-group: Crystals of *hornblende* in—fluor-spar, quartz, cobaltine, augite, garnet, idocrase, zircon, wernerite (scapolite), sodalite, nepheline, sanidin, anorthite, pennine (chlorite); of *actinolite, etc.*, in—quartz, axinite, adularia, tourmaline; of *amianthus* and *asbestus* of both augite and hornblende groups in—quartz, magnetite, gypsum, calcite, dolomite, augite, hornblende, garnet, prehnite, stilbite.

Endomorphs.—Minerals enclosed in *augite:* magnetite, pyrites, augite, hornblende, amianthus, asbestus, olivine, garnet, œrstedite, mica, leucite, nepheline, labradorite, apatite. In *hornblende:* calcite, augite, diallage, hypersthene, amianthus, asbestus, idocrase, mica, felspar, disthene (kyanite), chabazite, graustein (iserin), apatite. In *actinolite* and *anthophyllite:* quartz, magnetite, pyrites, pyrrhotine, chalcopyrite, olivine, garnet, mica, sanidin, lievrite, talc.

Pseudomorphs.—In forms of *augite:* quartz, hornblende, asbestus, garnet, mica, green earth, cimolite, serpentine, steatite, talc. In forms of *hornblende:* quartz, asbestus, green earth, mica, serpentine, steatite, talc, chlorite, chabazite.

Wedding noticed in the augite crystals of Vesuvian lavas a multitude of minute bubbles like what are seen in ice. Sorby found in similar crystals what he calls "glass cavities," containing at least two kinds of crystals, which sometimes project beyond the wall of the cavity, as if they were formed at the same time with the augite. Several Scottish augites have the same structure. Sorby has also found in many specimens of hornblende in blocks, on the Monte Somma, cavities partially filled with liquid. From the proportion of the volume of the fluid to the empty space, he calculates the temperature at which they were enclosed was 360° Cent.

FELSPAR GROUP.—The felspar group is the most important of all rock-forming minerals. The number of varieties which have received special names is very considerable, and until the researches of Sartorius von Waltershausen and Tschermak, their composition and relationships were very unsatisfactory. The former showed* that the variation in the amount of silica in the majority of felspars was too great to allow of their being considered as distinct mineral species, and that they were mixtures of some few definite bodies. These he assumed to be anorthite, albite, and krablite, a kind of felspar containing lime, so named by Forchammer, from Krabla, in Iceland, where it is found. Tschermak, following out Sartorius von Waltershausen's views, divides† the felspars crystallographically into two series: 1. *Orthoclase* (ὀρθός, straight, and κλάσις, cleavage), or monoclinic felspars; and 2. *Plagioclase* (πλάγιος, slanting or oblique, and κλάσις, cleavage), or triclinic felspars. He admits three definite chemical compounds:—

Orthoclase.	1. Orthoclase,	$K_2O,Al_2O_3,(SiO_2)_6$	$= K'_2Al'''_2Si_6O_{16}$
Plagioclase.	2. Albite,	$Na_2O,Al_2O_3,(SiO_2)_6$	$= Na'_2Al'''_2Si_6O_{16}$
	3. Anorthite,	$(CaO)_2,(Al_2O_3)_2(SiO_2)_4$	$= Ca''_2Al'''_4Si_4O_{16}$

Orthoclase and albite may be considered as acid felspars, in contradistinction to the anorthite or basic felspar. All other felspars are mixtures of these three. Tschermak, not admitting the isomorphism of potash and soda, considers that all

* *Ueber die Vulkanischen Gesteine in Sicilien und Island und ihre Submarine Umbildung*, 1853.

† *Die Feldspathgruppe. Sitzungsberichte der Akademie d. Wissenschaften zu Wien*, Bd. I. p. 566. 1864.

orthoclase crystals containing soda are simple mixtures; that is, that the crystals are built up of heteromorphic materials. Haidinger was the first to draw attention to the intergrowth of orthoclase and albite. In 1823 Gustav Rose showed that the orthoclase of Hirschberg, a well-known locality for that mineral, was a mixture of those two minerals. But it was Breithaupt's and Gerhard's investigation on perthite that clearly showed that many potash felspars consisted of alternate lamellæ of orthoclase and albite. In the case of perthite this alternation can be seen by the difference of colours; in other cases the cleavage planes show the twin striations. In some large opaque crystals the albite sometimes decays out almost wholly, and leaves a kind of skeleton of transparent or translucent orthoclase. The crystalline forms of albite and anorthite do not differ so much as those of albite and orthoclase; minerals formed of a mixture of the former are consequently more intimately mixed. Tschermak looks upon albite and anorthite as isomorphic. In doing so he excludes as a condition of isomorphism similarity of chemical constitution. According to him isomorphism is not an intrinsic property of the chemical atoms or molecules of a body; they are not like bricks, which, if they once fitted into a hole left by another, should do so on all occasions. The isomorphism of any two bodies depends upon certain conditions which may be fulfilled in one case and not in another. This view, while somewhat different from the isogonism of Laurent, is even a wider extension of the idea of isomorphism than he contemplated.

The angles of albite and anorthite do not differ from each other more than those of bodies usually considered isomorphic, or more correctly speaking homœomorphic; they resemble each other in optical properties, and there is a gradation as regards cleavage from albite to anorthite. Their atomic volumes approach closely, while albite differs somewhat in this respect from orthoclase. Thus:

		Molecular Weight.	Mean Specific Gravity.	Atomic Volume.
Orthoclase,	$K_2O,Al_2O_3(SiO_2)_6$	557	2·558	218
Albite,	$Na_2O,Al_2O_3(SiO_2)_6$	525	2·624	202
Anorthite,	$(CaO)_2(Al_2O_3)_2(SiO_2)_4$	558	2·758	200

The whole of the felspars have been classified into ten series. At one end stands the potash felspar, at the other the lime felspar: in the middle the soda felspar, albite. The following table gives the ten series, showing the limits of each series as regards the three constituents which characterise the fundamental felspars:—

Orthoclase group:—

Potash Felspars.	1. Adularia series,	16 to 13	per cent of potash, and	0 to 2	per cent of soda.
	2. Amazonite "	13 to 10	" "	2 to 5	" "
	3. Perthite "	10 to 7	" "	5 to 7	" "
	4. Loxoclase "	7 to 4	" "	7 to 10	" "

Plagioclase group:—

Soda Felspars.	5. Albite series,	0 to 2	per cent of lime, and	12 to 10	per cent of soda.
	6. Oligoclase "	2 to 6	" "	10 to 8	" "
Lime Felspars.	7. Andesin "	6 to 10	" "	8 to 5	" "
	8. Labradorite "	10 to 13	" "	5 to 3	" "
	9. Bytownite "	13 to 17	" "	3 to 1	" "
	10. Anorthite "	17 to 20	" "	1 to 0	" "

The following are the varieties included in each series:—1. *Adular* series—adularia, valencianite, paradoxite, rhyacolite; 2. The *Amazonite* series—amazon-

stone, pegmatolite, sanidin in part; 3. *Perthite* series—perthite, microlin, and sanidin and orthoclase in part; 4. *Loxoclase* series—loxoclase, orthoclase in part; 5. *Albite* series—(a) albite, pericline, tetartin; (b) hyposclerite, cleavalandite, oligoclase in part; (c) glassy albite, pantellarite; 6. *Oligoclase* series—(a) oligoclase, peristerite; (b) glassy oligoclase; 7. *Andesin* series—andesin, etc.; 8. *Labradorite* series—(a) labrador, saussurite; (b) glassy labradorite; 9. *Bytownite* series—bytownite; 10. *Anorthite* series—anorthite.

Endomorphs in orthoclase, etc.: quartz, anatase, rutile, specular iron, magnetite, pyrites, calcite, crichtonite (ilmanite), diopside, epidote, pinite, mica, titanite, tourmaline, chlorite, stilbite, samarskite (uranotantal), granite. In *sanidin:* quartz, crichtonite, augite, hornblende, mica, apatite. In *albite:* quartz, specular iron, amianthus and asbestus, mica, chlorite. In *pericline:* titanite, chlorite. In *labrador:* ilmanite, zircon, chlorite. In *oligoclase:* specular iron, pyrrhosiderite (göthite), oligoclase. In *anorthite:* chalcopyrite, hornblende.

Perimorphs.—Minerals enclosing *orthoclase, etc.:* fluor-spar, quartz, pyrites, hornblende, beryl, idocrase, axinite, adular in adular, tourmaline; enclosing *sanidin:* hornblende; enclosing *albite:* quartz, dolomite, garnet, pistacite, tourmaline; enclosing *oligoclase:* pistacite, oligoclase; enclosing *labrador:* augite.

NEPHELINE (from νεφέλη, a cloud, because the mineral is rendered dull by acids) is an alkaline aluminous silicate, sodium being the most abundant alkaline metal. It crystallises in tables and also in prisms of the hexagonal system: the surfaces of the prisms being rough. Its colours are white, greyish-white, grey, yellowish-grey, translucent to opaque. Hardness 5·5 to 6; specific gravity 2·58 to 2·65. Cleavage imperfect, parallel to base and faces of prisms. Its composition may be represented by the formula $M'_8[Al_2]_4Si_9O_{34}$, in which M′ represents sodium and potassium. Most of the analyses give the proportion of these metals as four atoms of sodium to one of potassium. Some specimens contain lime, sometimes to the extent of between three and four per cent. Most specimens also contain a little water.

Elæolite is a massive variety of nepheline, remarkable for its greasy lustre, from ἔλαιον, oil. The colours are dark green, greenish, and bluish or reddish-grey, with a peculiar sheen.

Nepheline, formerly believed to have a very limited diffusion, is now found to be an essential and frequent ingredient of rocks, especially basalts and lavas. Elæolite occurs only in the older rocks, such as the Norwegian zircon-syenite, nepheline in the newer. They stand towards each other somewhat in the same position as orthoclase does to sanidin.

LEUCITE (from λευκός, white) is a silicate of aluminium and potassium, sometimes part of the latter being replaced by sodium. It is represented by the typical formula $K_2Al_2Si_4O_{12}$. It occurs in the form of the ikosi-tetrahedron, or twenty-four-faced trapezohedron, and always ingrown; also in crystalline grains. The crystals are generally yellowish or greyish, white or ashy, and occasionally white, rarely translucent, generally opaque. Hardness 5·5 to 6; specific gravity 2·4 to 2·5; soluble in acids without gelatinising.

Leucite is a constituent of lavas and basic volcanic newer rocks. It has not yet been noticed in the older rocks. Leucite occurs associated with augite and magnetite; scarcely ever with hornblende. Leucite represents potash felspars in rocks, and is sometimes associated with sanidin, while nepheline appears to represent the lime felspars, but has never been observed associated with them. Nepheline and leucite occur very frequently together, but they appear never to occur singly or associated with quartz like the true felspars.

NOSEAN is a remarkable mineral, occurring crystallised in rhombic dodecahedrons and other forms of the monometric system, and containing from 7 to 10 per cent of sulphuric anhydride. It also occurs in crystalline grains. It is of an

ash-grey or yellowish-grey colour. It has a hardness of 5·5, and a specific gravity of 2·25 to 2·27. Its composition may be represented by the formula $2NaCl,3Na_2Al'''_2Si_2O_8 + 5(2Na_2SO_4,6Na_2Al'''_2Si_2O_8)$; that is a union of one molecule of sodalite and five of a soda-haüyne. Nosean is a constituent of the nosean-phonolite of the Lake of Laach on the Rhine. It is named in honour of a mining engineer named Nose.

Haüyne is a bright blue or sometimes asparagus-green mineral, found in lavas, generally in crystalline grains, but sometimes in rhombic dodecahedrons. Its hardness is 5 to 5·5, and its density 2·43 to 2·83. It is decolorised when heated, as if the colour was due to a sodic combination of sulphur, like that in ultramarine. There are apparently three varieties—that of Monte Albano, that of Monte Somma (Vesuvius), and that of Niedermendig, near the Rhine. The first may be represented by the formula $3(Na_2Al_2'''Si_2O_8) + 2(Ca''SO_4)$; the second by $2(Na_2Al'''_2Si_2O_8) + CaSO_4$ — potassium is generally present also; the third, or Niedermendig, variety is considered to be composed of two molecules of the first or Albano-haüyne, with one of nosean. Haüyne is an essential constituent of haüyne-porphyry, and occurs in several other rocks. It is named in honour of the celebrated Haüy.

Nosean and haüyne represent in a certain sense for the newer and non-quartzose rocks the garnets of the older rocks. They are also isomorphous with the garnets. *Ittnerite*, which is usually included among the zeolites, appears to be hydrated nosean, at all events a mixture of hydrated sodalite and haüyne like that mineral does occur.

Pseudomorphs.—In the form of *nepheline:* sodalite, mesotype, lithomarge. In the form of *leucite:* felspar, kaolin.

Mica is a term applied to several minerals differing considerably in chemical composition, and belonging to several crystalline series, but all distinguished by being easily cleavable into thin laminæ. This laminar structure is hence termed micaceous. It is probable that all micas crystallise in the rhombic or trimetric system. They are also all biaxial, that is, have two optic axes, though one of the commonest distinctions made between micas is the classification into uniaxial and biaxial micas. In most of the so-called uniaxial micas the angle between the optic axes is so small, being in phlogobite sometimes less than 5°, and rarely reaching 20°, while in biotite they intersect at angles of from 1° to 2°; and the plates that can be examined so thin that the existence of the double axes can rarely be ascertained. In the micas, hitherto always recognised as biaxial, on the other hand, the angle varies from 45° to 75°. Although there are really no uniaxial micas, the old distinction is of practical value, because the high-angled micas rarely ever contain magnesia, while the low-angled ones contain from about 4 to 30 per cent, and, except rarely, above 20 per cent.

Chemically we may divide the micas into: 1. Non-magnesian; and, 2. Magnesian micas. The non-magnesian ones are generally called potash micas. This is, however, liable to lead the student to suppose that the magnesian micas contain no potash. All micas do, however, contain potash, though in general the magnesian ones contain somewhat less than the non-magnesian. The non-magnesian micas may be conveniently divided into: 1. Common mica or muscovite, not containing lithia; and, 2. Lithia micas or lepidolite.

Muscovite, common or biaxial mica, occurs in forms which look very like monoclinic prisms, but which de Sénarmont and von Kokscharow consider to be rhombic or trimetric, and usually hemihedral. The cleavage is basal,—eminent. Twins are frequently formed parallel to the faces of the prism. The colours are white, grey, pale green, sometimes dark olive-green, brown, and violet-yellow. Muscovite is remarkable for the size of the folia which can be obtained. It also forms aggregations of small foliated crystals, arranged into stellar and plumose groups. In thin plates it is always transparent; in thick plates apparently opaque. Its hardness is from 2 to 3; its specific gravity 2·8 to 3·1.

The silica varies from 44·6 to 48 per cent; the alumina from about 30 to 38·4 per cent; potassium, estimated as potash, is usually about 10 per cent. Muscovite always contains water—some specimens containing as much as 6 per cent. The presence of water facilitates the decomposition of the mica, the alkalies and iron being gradually removed; the progress of the decomposition is indicated by the loss of elasticity and transparency of the plates. The non-magnesian *fuchsite* or chrome-mica belongs to this type. A specimen analysed by Schafhäutl contained 3·95 per cent of chromic oxide. Many other biaxial micas also contain traces of chromium. There are several varieties of muscovite differing chiefly in colour, that is, in the proportion of iron, etc., which they contain, and also, no doubt, in the proportion of water. Several of these varieties get special names, and are looked upon as distinct minerals: such as *margarodite*, *gilbertite*, *damourite*, *sericite*, etc.; but they are really only altered mica.

Lepidolite or lithia mica, occurs usually in granular masses, consisting of foliated scales. It also occurs in oblique rhombic and six-sided prisms. In hardness and lustre, and often in colour, it agrees with muscovite. When free from iron, and containing manganese, it is of a beautiful rich to pale lilac colour. Small traces of iron give it a red tinge. Some mineralogists restrict the name lepidolite to the rose-red and lilac varieties. Lithia micas contain more fluorine than common mica: the amount varies from 2 to 8 per cent. A specimen of the mica of Juschakowa in the Ural gave on analysis as much as 10·22 per cent. The true lepidolite or lithia micas, free from iron, contain from 49 to about 52 per cent of silica, from 26·7 to about 28·5 of alumina, and about 10 per cent of potash. The lithia varies from a little over 1 per cent to 6 per cent. Many lithia micas contain sodium, and perhaps rubidium and cæsium, but not magnesium, or only traces. Lithia mica sometimes replaces common mica in granite; when not containing manganese, and comparatively free from iron, they can scarcely be distinguished from common mica.

The magnesian micas may also be conventionally divided into two species, though there is really no absolute line of demarcation between them—namely, phlogobite and biotite.

Phlogobite occurs in rhombic prisms, which are sometimes truncated on two edges, so as to produce hexagonal prisms. The colour is sometimes white, or of various shades of brown, but usually it is of a ferruginous coppery-red or yellow. The analyses made give the variation of the silica from 37·5 to 42·6 per cent, of the alumina from about 17 to 20, and of the magnesia from 26 to 30·3 per cent. The amount of iron is generally small, and is probably always present as ferrosum. The potash varies from 6 to 10·5 per cent, part of it being replaced by soda. This kind of mica is very subject to alteration from hydration. The alteration is first indicated by spots on the foliæ, due, perhaps, to oxidation of the iron, and the decomposition of the sides of the prism. Phlogobite is sometimes associated with apatite, and almost always contains some phosphoric acid. It is found in granular limestones and other recent rocks.

Biotite occurs in hexagonal prisms, produced by the truncation of the diagonal edges of a rhombic prism. The prisms are usually tabular, and cleave with remarkable facility parallel to the base. It also occurs in foliated masses. When it contains little iron it is white, but usually it is green, brown, or almost black, owing to the quantity of iron. The silica varies from about 39·5 to 47·6, being usually about 40 to 42 per cent. The alumina varies from 9 to 19 or 20 per cent. The iron appears to exist in great part as ferricum, and varies from about 5 to 37 per cent, the magnesia from 26 to a little more than 3 per cent, as in the so-called *lepidomelan* or black mica found in some granites; it is, however, usually above 20 per cent, a small percentage of magnesia being always accompanied by a high percentage of iron. The potash varies from 4·6 to 10·8, there being generally some soda where the percentage is low. The magnesian

varieties of fuchsite or chrome mica, of a beautiful green colour, and containing nearly 6 per cent of chrome, belong to this species.

The composition of the micas cannot as yet be represented truly by formulæ. The magnesian micas appear to be ortho-silicates in which the silica is not condensed. They may be approximately expressed by a general formula, $(M'_4SiO_4)m(M''_2SiO_4)n([Al'''Fe''']_4Si_3O_{12})p$, in which the co-efficient m expresses the number of molecules of alkaline ortho-silicates, n that of the magnesian and ferrous silicates, and p that of the silicates of aluminium and ferricum. The non-magnesian micas may, according to Rammelsberg, be approximately expressed by $M'_4Si_3O_8.n([Al'''_2Fe'''_2]_2Si_3O_{12})$. The silicate of alumina and iron, forming the second part of this formula, is an ortho-silicate like that in the magnesian micas, but the silicate of the alkalies, represented by M', is an anhydro-silicate representing the condensed acid $H_4Si_3O_8$.

Perimorphs of mica: fluor-spar, quartz, corundum; chrysoberyl; pyrites; calcite, chalybite, augite, hornblende, actinolite, spodumene, beryl, garnet, zircon, idocrase, wernerite, meionite, sodalite, haüyne, nepheline, lepidolite, mica, felspar, sanidin, albite, andalusite, topaz, ilmenite, apatite.

Endomorphs in mica: quartz, rutile, limonite, augite, garnet, tourmaline, astrophyllite, apatite. Brewster found in a thick plate of mica from Siberia the remains of small animals (acarus), from 0·30 to 0·15 of millimetre long. Some were enclosed in cavities, around which the mica appeared to be optically complete. The animals must have got in through fissures, which afterwards closed.

Pseudomorphs.—In the form of mica: quartz, steatite. *Mica* in the form of: augite, hornblende, beryl, idocrase, scapolite (wernerite), epidote, dichroite (pinit, fahlunite, esmarckite, bonsdorfite, chlorophyllite, weissite, praseolite, pyrargillite, gigantolite), orthoclase, albite, labradorite, elæolite, andalusite, kyanite, tourmaline.

CRYSOLITE or PERIDOTE is an ortho-silicate of magnesium Mg''_2SiO_4, in which more or less of the magnesium is displaced by iron, so that its formula is always a multiple of that just given. It crystallises in trimetric prisms of a yellowish or olive green; it also occurs in granular masses or imbedded grains. The transparent crystals are distinguished as *chrysolite;* the imbedded masses and grains are *olivine*, from their olive colour. There are several varieties of this mineral, among which may be mentioned the aluminous variety, *hyalosiderite.* Olivine is a characteristic mineral of basalt, and the recent researches of Tschermak on the porphyritic rocks of Austria show that it is one of the most important constituent minerals of other crystalline rocks also.

GARNETS are also ortho-silicates, and may be represented by the general formula $M''_3Al_2Si_3O_{12}$, or otherwise $(M''O)_3Al_2O_3(SiO_2)_3$, or rather the double of it $M''_6Al'''_4Si_6O_{24}$, or $(MO)_6(Al_2O_3)_2(SiO_2)_6$, in which M'' represents calcium, magnesium, iron, or manganese. Garnets almost invariably contain more than two bases, so that the four isomorphic metals may be associated in twelve different ways. When lime predominates, it is *grossular*, if greenish; *cinnamon stone*, if yellowish-brown; *topazolite*, etc., if of the colour of topaz. When magnesium predominates it forms the *magnesia garnet;* when iron predominates it is the *iron garnet* or *almandine*, to which the *common* and *noble garnet* belong. The manganese garnet is known as *spessartine.* The *iron-lime garnet* is *melanite* when of a velvet-black colour. It is called *colophonite* when it consists of a granular mass of small crystals having a resinous lustre and a brown colour. It is the *aplome* when of a brown or orange-brown colour, and having the faces striated.

Garnet crystallises in the monometric or regular system, and principally in the form of the rhombic dodecahedron, or modifications of it. Besides occurring as an accidental ingredient of many crystallised and altered rocks, it also forms one of the constituent minerals of the rocks eklogite, garnet rock, the Swedish rock, eulysite, and kinzigite.

Endomorphs.—Garnet has been found in quartz, martile, dysluite, galena, molybdenite, calcite, augite, actinolite, beryl, garnet, idocrase, mica, sodalite, nepheline, sanidin, staurolite, tourmaline. Garnet has been found as a *perimorph* of the following minerals:—fluor-spar; quartz, rutile, magnetite, oxide of iron; pyrites; chromate of iron; calcite; diopside, hornblende, garnet, idocrase, epidote, mica, albite, disthene, titanite, vorhauserite (serpentine).

Pseudomorphs.—Garnet in the form of: augite, serpentine, talc, chlorite; and epidote in the form of garnet.

ZIRCON is an ortho-silicate of Zirconium, $Zr.SiO_4$ or $Zr.O_2SiO_2$, which crystallises chiefly in combinations of the octahedron and prism of the dimetric or tetragonal system. The crystals are generally coloured red, yellow, or brown, but are sometimes found colourless. The colour is due to ferric oxide. Its hardness is considerable, being 7 to 8, and its density from 4·4 to 4·7. It is an essential constituent of the zircon-syenite of Norway, and occurs occasionally in a large number of crystalline rocks of all ages.

EPIDOTE.—This mineral is closely related to garnet, by the alteration of which it is frequently produced. It appears to contain generally, if not always, some basic water, and may be represented by the formula $H_2M''_6[M'''_2]_4Si_9O_{37}$. Lime-iron garnet is readily converted into it by the oxidation of the iron, the separation of lime or iron as carbonate, and the addition of water—thus, three molecules of a garnet, having the composition $Ca''_4Fe''_2Al'''_4Si_6O_{24}$, or

$$Ca''_{12}Fe''_6Al'_{12}Si_{18}O_{72} + O_2 + 2H_2O + 2CO_2 = 2[H_2Ca''_5Fe''Fe'''_2(Al_2)_3Si_9O_{37}] + CaCO_3.$$

This equation explains the facility with which common garnet passes into epidote; and also why lime garnets free from iron do not produce epidote by their decomposition. As in the garnet family, so in this, M'' represents calcium, magnesium, iron (ferrosum), and manganese; there are consequently a number of varieties of epidote, according as one or the other of these metals predominates. The lime epidote includes the mineral called *zoisite*. It may be represented by the formula $H_2Ca''_6[Al'''_2]_4Si_9O_{37}$, which differs from common epidote by the Fe'''_2 of the latter being represented by Al'''_2 in zoisite. The latter sometimes contains epidote, and must therefore be sometimes formed at the same time; but the conditions for its formation are quite different. Indeed, the two minerals appear to belong to different series, at least the cleavage and some other physical properties of zoisite differ from those of epidote. Possibly *thulite* is the true lime epidote. The lime and iron variety is *epidote* proper, also called *pistacite*.

Epidote crystallises chiefly in prisms of the monoclinic system. Its hardness is from 6 to 7, its sp. gr. from 3·2 to 3·5. It is almost always coloured, especially of a greenish-yellow, oil green, to blackish-green; very rarely red.

Epidote forms the chief part of a very uncommon rock, epidosite; it is also a very widely-diffused mineral in older crystalline rocks. Meionite, which crystallises in the dimetric or tetragonal system, may be represented by the formula $Ca''_6[Al_2]_4Si_9O_{36}$, which represents anhydrous lime epidote, of which it may be a dimorphic form.

SCAPOLITE or WERNERITE is essentially a silicate of aluminium and calcium, but it is very subject to change, and contains generally potassium, sodium, magnesium, and water. It crystallises in prismatic forms of the dimetric system, which scarcely differ from those of meionite. Indeed, those specimens which have the composition of that mineral are regarded by many mineralogists as the original scapolite. The lime varies from about 20 to about 3 per cent, the silica from about 43 to 60 per cent—the high lime and low silica limits representing generally the meionite type, of which it may perhaps be merely an altered form. Its colours are chiefly grey, a light yellowish or green, more rarely red, generally opaque, and scarcely translucent on the edges. It has very much the appearance

of a felspar.* Scapolite occurs as an occasional mineral or granite and granular limestone, and forms almost wholly scapolite rock.

CORDIERITE, DICHROITE, or IOLITE, is a silicate of aluminium and magnesium, which may be represented by the typical formula $Mg''_2[Al_2]_2Si_5O_{18}$; part of the magnesium is, however, sometimes replaced by iron (ferrosum Fe''), and part of the aluminium, perhaps always, by iron Fe'''_2 (ferricum). It occurs in thick prisms of the trimetric or rhombic system, which are often hexagonal. Its colours are, various shades of blue, sometimes smoky blue; when of the latter colour it is called *peliom.* It is often of a deep blue colour along the principal axis, and of a brownish-yellow or yellowish-grey along the secondary axes, that is perpendicular to the principal axis. It derives its name, dichroite, from this circumstance. The crystals are either transparent or translucent, have a specific gravity of 2·6 to 2·7, and a hardness from 7 to 7·5. Cordierite occurs very frequently in gneiss, granite, and talcose slate, and is an essential constituent of cordierite gneiss. It does not occur in the newer rocks,—it is, as Quenstadt says, as characteristic of the old rocks as olivine is of the newer ones.

Cordierite is acted upon with such great facility by water holding carbonic acid and alkaline and other salts in solution, that cordierite is almost always found in an altered state. The alterations consist either of simple hydration, the removal of the divalent metals by water and carbonic acid, or the addition of iron, alkalies, etc., introduced into them by water. Among the hydrous cordierites may be mentioned *bonsdorfite*, which occurs in Finland granite, and is perhaps trihydrated cordierite; the monhydrated American *chlorophyllite*, *esmarckite*, and *praseolite* from the gneiss of Bräkke near Brevig in Norway, which is sesquihydrated. There are many other of those hydrated serpentine-like altered dichroites, which differ more or less from the unaltered mineral in composition, such as the *gigantolite* of the granite of Tammela in Finland, the *aspasiolite* of the hornblende gneiss of Kraggeroe in Norway, the *pyrargilite* of Helsingfors, the *fahlunite* of the talc-slate of Fahlun in Sweden, the *iberite* from Montoval near Toledo in Spain, the *oosite* of the porphyries of Geroldsau near Baden-Baden. One of the most widely-diffused minerals occurring in granites is *pinite*, from which the whole of these minerals are sometimes termed the pinatoid group. The composition of this mineral varies very considerably; besides containing water, it always contains potash, varying from about 6 to 12 per cent. The variation in the quantity of alkali and of water —the latter varies from a little over 1 per cent to 8 per cent—shows that *pinite* includes cordierites in various stages of alteration. All the pinatoid minerals are either accompanied by unaltered dichroite, or contain frequently a nucleus of that mineral.

TOURMALINE or SCHORL, like garnet, epidote, etc., includes a number of varieties differing more or less in chemical composition, but crystallographically and physically well defined. They usually occur in long or short prisms of the hexagonal system, generally striated along their length, and terminated by single or double rhombohedral ends. Sometimes the crystals are thus terminated at only one end, they are then said to be hemimorphic. Most hemimorphic crystals exhibit polar electricity when heated and cooled. Tourmalines are very complex in chemical composition. They are essentially silicates of aluminium and magnesium— the aluminium being represented in part by boron, the magnesium by iron Fe'' (ferrosum) or manganese Mn''. All tourmalines contain potassium and sodium, and some lithium also; they also contain fluorine, replacing part of the oxygen. The constant presence of alkalies seems to indicate that the tourmalines consist of two

* Scheerer first suggested that it was dimorphic with lime felspar, an opinion admitted by many. It should, however, be always recollected that dimorphism implies either that the bodies are isomeric, but having differently-constituted molecules, or condensed, and therefore totally different molecules.

distinct silicates, one of which may be analogous to, if not identical with, potash-mica, and in the lithian tourmalines with lepidolite. Rammelsberg divides the tourmalines into : 1. Magnesia tourmalines,—yellow and brown coloured, and free from lithium ; 2. Magnesia-iron tourmalines,—black by reflected light, but greenish or brownish by transmitted light, and not containing lithium ; 3. Iron tourmalines, —black, not containing lithium ; 4. Iron-manganese tourmalines,—dark violet, blue, green, and containing lithium ; 5. Manganese tourmalines,—red, and colourless, and containing lithium. The iron or black tourmalines are sometimes called *schorl ;* the red or manganese tourmalines include the varieties *rubellite, siberite, daourite,* and *apyrite ;* the white are sometimes called *achroite.*

In the present state of our knowledge tourmalines cannot be represented by a formula. The student will find in Dana's *Mineralogy* and Rammelsberg's *Mineral Chemie* the tabulated results of the analyses of the different varieties, for which we are mainly indebted to Rammelsberg. Black opaque tourmaline or schorl forms, with quartz, the rock known as Tourmalin-rock. It is also present as an occasional mineral in granite, gneiss, mica-, talc-, and chlorite-slates, hornblende-rock, granular limestone, etc. It does not occur in the newer crystalline rocks.

Magnesian Hydrous Silicates.—TALC is a hydrated silicate of magnesium, probably a meta-silicate of the composition $H_2Mg''_5Si_6O_{18}$, representing the acid $H_{12}Si_6O_{18}$. It rarely occurs in distinct crystals which are rectangular or hexagonal plates, scales, or tables having eminent basal cleavage, and belonging either to the trimetric or monoclinic systems. *Foliated talc* is of this kind. It also occurs in globular or stellated groups. Its most usual mode of occurrence is granular, massive to impalpable. In thin plates it is sub-transparent to sub-translucent ; it is highly sectile. The thin laminæ are flexible, but not elastic. The colours are—white or silvery-white, greyish, greenish-grey, apple to leek and oil-green. On the cleavage faces the lustre is pearly. It has a greasy feel. It forms talc-slate, and is said to occur sometimes in granite in place of mica. Talc is a frequent product of the decomposition of hornblende and augite. The change is very simple, as they are all meta-silicates. Some talcs contain alumina, generally, no doubt, representing kaolin, and derived from the decomposition of the felspars in aluminous augites and hornblendes. In the pure talcs the silica varies from 59 to 63 per cent, being most frequently from 61 to 62 per cent ; the magnesia from 30 to 33 per cent. The water is very variable, from mere traces to nearly 7 per cent.

Steatite or *soapstone* is a coarse greyish-white, greyish-green, or yellowish variety of impure talc. It is sometimes granular, of fine texture, or lamellar, but usually compact. It is very greasy to the feel. The steatite of Briançon, known as "French chalk," is white. *Potstone* or *lapis ollaris* includes the impurer granular dark-coloured varieties. The compact hard slaty talcs are called *indurated talc.* Some indurated talc-slate is yellowish and translucent in thin plates. *Meerschaum* is a hydrated silicate of magnesium of a different composition, and of different origin from talc. There appear to be two hydrates, $Mg''Si_3O_8,H_2O$ and $Mg''Si_3O_8,2H_2O$, included under this name. Meerschaum appears to be connected with the decomposition of dolomites.

Pseudomorphs.—Talc occurs in the forms of the following minerals :—augite, hornblende, garnet, andalusite, cordierite, tourmaline. Steatite occurs in the following forms :—fluor-spar, quartz, spinel, barytes, calcite, dolomite, augite, hornblende, crysolite, garnet, idocrase, scapolite (wernerite), cordierite, mica, felspar, andalusite, kyanite, tourmaline, phillipsite, chabazite, mesotyp.

SERPENTINE is also a hydrated silicate of magnesium. Its typical formula appears to be $Mg''_3Si_2O_7,2H_2O$, corresponding to the first para-silicic acid $H_6Si_2O_7$. The composition, according to this formula, would be 44·14 of silica, 42·97 of magnesia, and 12·89 of water. It forms a compact, generally impure, green-coloured mass, from granular to impalpable ; it also occurs fibrous and foliated.

Its sp. gr. is from 2·507 to 2·591. Some of the fibrous varieties have a density of only 2·2 to 2·3. The hardness varies from 3 to 4, but sometimes, though rarely, it reaches 5. Serpentine exhibits a great variety of colours; the predominant ones are shades of dark green, which pass on the one side into almost black, and on the other to lighter colours, through olive-green, leek-green, oil-green, pistachio-green, to siskin-green. Yellow, brown, red, to blood-red colours also occur. These colours generally occur as clouds, veins, spots, which run into one another, and produce considerable play of colours. Delesse has shown that these shades of colour depend upon the quantity of iron, its degree of oxidation, and state of combination. He also observed that in many cases the green or black coloured parts formed veins and bands in a regular manner in the brown-coloured parts. The darker parts are due to the action of water containing oxygen, which penetrated along fine fissures, often no longer visible, or portions of the rock which were more porous than other parts. Several varieties of serpentine are distinguished by special names, such as *common* and *noble serpentine;* the fibrous or asbestiform serpentine—*picrolite, baltimorite, chrysotile, metaxite;* the foliated kind called *marmolite;* and the resinous or *retinalite.* The fibrous varieties are of very great importance in connection with the genesis and metamorphism of serpentine and several other rocks. All the fibrous varieties have the same composition, and are apparently but regenerations of the serpentine in fissures and cracks. Naumann has remarked that serpentine is intersected with a net-work of fibres, just as compact gypsum is by fibrous gypsum.

Endomorphs.—Serpentine is remarkable for the number of minerals which occur in it. Among them may be mentioned quartz, chalcedony, jasper, chrysoprase, semi-opal, specular iron, magnetite, pyrites, mispickel, chromate of iron, hornblende, bronzite, diallage, garnet, pyrope, chlorite, calcite, dolomite, the compact snow-white dolomite called gurhofian, magnesite, brucite, and the fibrous variety of that mineral called nemalite, the hydrous aluminate of magnesium hydrotalcite, and the corresponding one containing ferric oxide, replacing part of the alumina called völknerite, the hydrous silicate of magnesium, kerolite, and the ferruginous variety of it, dermatin, etc.

Pseudomorphs.—Serpentine is found in forms of the following minerals:—Brucite (hydrate of magnesium), spinel, dolomite, penkatite, $Ca''CO_3, Mg''(Ho)_2$, augite, hornblende, chrysolite, iron garnet.

Chlorite.—This term is applied to several minerals of analogous composition, and very similar in appearance, but perhaps not really belonging to the same series. The variety called *pennine,* from Zermatt in the Valais, is said to crystallise in the hexagonal system, usually in six-sided tables, with straight or bevelled edges. Chlorite, from the well-known mine of Ackmatowsk, in the Southern Ural, on the other hand, is monoclinic. Chlorite occurs generally in platy, scaly, or fine earthy aggregates. The laminæ of chlorite are flexible, but not elastic. The hardness is 2 to 2·5; the density from 2·65 to 2·85. It is usually of a leek, olive, and blackish green. The crystals are of a dull emerald green in the direction of the axis; of a yellowish or hyacinth red at right angles to it: it is sometimes silver-white. Chlorite appears to be a combination of the silicate which exists in serpentine with aluminate of magnesium $Mg''Al'''_2O_4.Mg''_3Si_2O_7, 2H_2O$; but part of the magnesium is almost invariably replaced by ferrous oxide. The silica varies from about 30 to 34 per cent, the alumina from 10 to 20 per cent, the magnesia from 32 to 37 per cent, the iron calculated as ferrous oxide from 0 to 11 per cent, and the water appears to be pretty constant between 12 and 13 per cent.

Delessite is a ferruginous chlorite, occurring in many amygdaloids. It appears to differ somewhat in composition from chlorite proper. *Ripidolite* is a mineral very like chlorite in appearance and chemical composition, and like the Ural variety monoclinic, as Descloizeaux has shown. It is very difficult to express the results of the analyses of it by a formula. The following has been proposed:—

$M''_3Al_2O_6,4M''SiO_2,6H_2O$—$M''$, representing ferrous oxide and magnesia in proportions of 1 : 3, 1 : 1, etc. Ripidolite is a constituent of rocks in Ireland and Scotland.

Perimorphs.—Chlorite has been found enclosed in fluor-spar, quartz, rutile, magnetite, calcite, beyrl, helvin, axinite, praseolite (altered cordierite), adular, albite, pericline, labradorite, titanite, tourmaline, chabazite. *Ripidolite* in idocrase. *Endomorphs.*—Chlorite has been observed enclosing rutile and tourmaline, and pennin hornblende.

Pesudomorphs.—Chlorite has been found in forms of quartz, magnetite, hematite, limonite, calcite, hornblende, garnet, felspar.

Non-Magnesian Hydrous Silicates.—Zeolites.—The term non-magnesian does not imply a total absence of that metal, but is a convenient term to distinguish a numerous class of hydrated double silicates in which magnesium is either wholly absent or is present in small quantities. Among these the most important class is the group of hydrous aluminous silicates, containing lime, or baryta, or lime potash, or soda, and called zeolites from ζέω I boil, and λίθος a stone, in reference to their property of boiling up from the escape of water when heated by the blow-pipe. They are very closely related to the felspars. Several of them may, indeed, be regarded as hydrated felspars. If we classify them in the order of the number of atoms of silicon condensed in each, the principal zeolites may be arranged as follows:—

Si_3.—$Na'_2Al'''_2Si_3O_{10}, 2H_2O$ Natrolite or soda mesotype.
$Ca''Al'''_2Si_3O_{10}, 3H_2O$ Scolecite proper.

$$\left.\begin{array}{l} a,\ [\overset{\text{Natrolite.}}{Na_2Al'''_2Si_3O_{10}, 2H_2O}]_3+[\overset{\text{Scolecite.}}{Ca''Al'''_2Si_3O_{10}, 3H_2O}]_7 \\ \text{and } b,\ Na'_2Al'''_2Si_3O_{10}, 2H_2O+[Ca''Al'''_2Si_3O_{10}, 3H_2O]_2 \end{array}\right\} = \text{Mesolite.}^{*}$$

$Ca''Al'''_2Si_3O_{10}, 4H_2O$ Levyne.
$Ca''_2Al'''_2Si_3O_{11}H_2O$ Prehnite.
Si_4.—$Na'_2Al'''_2Si_4O_{12}, 2H_2O$ Analcime.
$Ca''Al'''_2Si_4O_{12}, 3H_2O$ Caporcianite.
$Ca''Al'''_2Si_4O_{12}, 4H_2O$ Laumontite.
$[Ca''Na_2K_2]''Al_2Si_4O_{12}, 6H_2O$ Chabazite.
$[Na_2Ca''K_2]''_2Al_2Si_4O_{12}, 6H_2O$ Gmelinite or soda chabazite.
$[Ca''Al'''_2Si_4O_{12}, 5H_2O]^2 + K_2'Al'''_2SiO_4O_{12}, 5H_2O$ = Lime-harmotome.
$[Ca''; Na'_2]_2''Al'''_4Si_4O_{16}, 5H_2O$ Thomsonite.
S_5.—$Ba''Al_2Si_5O_{14}, 5H_2O$ Baryta-harmotome.†
S_6.—$Ca''Al'''_2Si_6O_{16}, 5H_2O$ Heulandite, etc.
$[Ba'': Sr'']''Al'''_2Si_6O_{16}, 5H_2O$ Brewsterite.
$[Ca'': Na_2]''Al'''_2Si_6O_{16}, 5H_2O$ Epistilbite.
$Ca''Al'''_2Si_6O_{16}, 6H_2O$ Stilbite or Desmine.

The whole of the minerals included under the designation zeolites appear to be reducible to a very few simple typical formulæ. If we represent the divalent metals, barium, calcium, magnesium, ferrosum, by M'', and the monivalent metals, potassium and sodium, by M', and exclude baryta-harmotome, which probably may be reduced to the same typical formula as lime-harmotome, all the preceding

* It is probable that the SiO_2 is too high, and that the true formula is $Ba''Al_2'''Si_4O_{12}$ $5H_2O$.

† *a* Represents several varieties of scolecite, among which may be mentioned *antrimolite*; *b* includes, among other scolecites or mesolites, *harringtonite*.

zeolites, and indeed nearly all zeolites, may be represented, exclusive of their water of crystallisation, by the following formulæ :—

I. $[M'_2 ; M'']''Al'''_2Si_3O_{10}$	Mesotype group—natrolite, scolecite, mesolite, etc.
II. $[M'' ; M'_2]''_2Al'''_2Si_3O_{11}$	Prehnite group.
III. $[M'' ; M'_2]''Al'''_2Si_4O_{12}$	Chabazite group—chabazite, gmelinite, analcime, caporcianite, laumontite, lime-harmotome, etc.
IV. $[M'' ; M'_2]''_2Al'''_4Si_4O_{16}$	Thomsonite group—thomsonite, comptonite, etc.
V. $[M'' ; M'_2]''Al_2Si_6O_{16}$	Stilbite group—heulandite, brewsterite, epistilbite, stilbite or desmin, etc.

Prehnite differs from scolecite and other calcareous members of the mesotype series by containing $2H_2O$ less and CaO more. It is worthy of note that prehnite is almost always associated with calcite, so that it is formed in the presence of an excess of lime. The relation of the zeolites to the felspars is very interesting; thus, thomsonite may be looked upon as hydrated anorthite, in which one atom of lime is replaced by two of sodium. Now thomsonite is always formed from labradorite, which is a mixture of anorthite and albite. Labradorite consists of—$Na_4Ca_6Al'''_{16}Si_{24}O_{80} = 2Na'_2Al'''_2Si_6O_{16} + 3Ca''_2Al'''_4Si_4O_{16}$, or two molecules of albite and three of anorthite. The anorthite produces thomsonite, by exchanging some lime for an equivalent quantity of soda and taking up water; while the albite, by the loss of two of silica and the gain of two of water, would produce analcime. The lime exchanged for soda might convert analcime into laumontite,—these being the minerals generally associated with thomsonite. Or labradorite might produce natrolite, scolecite, or the compound of both—mesolite.

The six atoms of silicon contained in the molecules of albite and orthoclase appear to divide into two groups of four atoms and two atoms, with much greater facility than into two groups of three each. Indeed, it is probable the latter decomposition only takes place in the mixed felspars containing anorthite. Tschermak has pointed out this interesting fact about the constitution of the albite and orthoclase molecules. Their decomposition into zeolites and into kaolin on the one hand, and their re-formation as pseudomorphs of the same zeolites, shows this division of the silicon in a striking manner.

Decomposition of Potash and Soda Felspars.

$$\underset{\text{albite}}{Na'_2Al'''_2Si_6O_{16}} + 2H_2O = \underset{\text{analcime}}{Na_2Al'''_2Si_4O_{12}\,2H_2O} + 2SiO_2$$

$$\underset{\text{orthoclase}}{K_2Al_2Si_6O_{16}} + CaO + 4H_2O = \underset{\text{laumontite}}{Ca''Al_2Si_4O_{12}, 4H_2O} + K_2O + 2SiO_2$$

$$\underset{\text{orthoclase}}{K_2Al_2Si_6O_{16}} + 2H_2O = \underset{\text{kaolin}}{H_4Al'''_2Si_2O_9} + K_2O + 4SiO_2$$

Re-formation of Felspars as Pseudomorphs of Zeolites and Leucite.

$$\underset{\text{analcime}}{Na''_2Al''_2Si_4O_{12}, 2H_2O} + K_2O + 2SiO_2 = \underset{\text{orthoclase}}{K_2Al'''_2Si_6O_{16}} + Na_2O + 2H_2O$$

$$\underset{\text{laumontite}}{Ca''Al_2Si_4O_{12}, 4H_2O} + K_2O + 2SiO_2 = \underset{\text{orthoclase}}{K_2Al'''_2Si_6O_{16}} + CaO + 4H_2O$$

$$\underset{\text{laumontite}}{Ca''Al'''_2Si_4O_{12}, 4H_2O} + Na_2O + 2SiO_2 = \underset{\text{albite}}{Na_2Al'''_2Si_6O_{16}} + CaO + 4H_2O$$

$$\underset{\text{leucite}}{K_2Al'''_2Si_4O_{12}} + 2SiO_2 = \underset{\text{orthoclase (sanidin)}}{K_2Al'''_2Si_6O_{16}}$$

It is scarcely necessary to remind the student that the potash, soda, lime, and silica removed or added in the foregoing equations do not take part in the reac-

tions as such, but are in combination—the bases as carbonates or silicates, the silica as silicates or silicic acid.

One of the bodies produced by the decomposition of potash and soda felspars in the preceding reactions, *kaolin*, is of special importance to the geologist. It is the type of those immense masses of amorphous hydrous aluminous silicates which are called by the general name of *clay*. Most clays contain considerable quantities of iron, which, when present as ferricum, colours them red. Clays also contain more or less of the debris of the rocks from which they are formed in all stages of decomposition.

Kaolin and clays are all derived from the decomposition of potash and soda felspars. Anorthite or lime felspar, which contains only four atoms of silicon in its molecule, does not yield kaolin, although its molecule, $Ca''_2Al''_4Si_4O_{16}$, contains the materials of two molecules of kaolin, by the addition of four molecules of water and the removal of two atoms of lime, thus--

$$Ca''_2Al_4Si_4O_{16} + 4H_2O = (CaO)_2 + 2H_4Al_2Si_2O_9 \text{ or } 2Al'''_2Si_2O_7,2H_2O.$$

The fact that anorthite does not produce kaolin, notwithstanding the simplicity of the reaction just indicated, is of very great interest, and throws great light on the constitution of the felspars.

There are several other amorphous hydrous aluminous silicates, such as hal loysite, samoite, smectite, pholerite, etc., which are not produced in the same way as kaolin. Many of them are precipitates from solutions, such as the indurated ones accompanying pyrites in lodes, the similar substances found in dykes, mineral veins, and in certain thin beds of various ages.

There are also several crystallised non-magnesian hydrous silicates, with and without alumina, which are often included under the term zeolites, but which are separated from them by most mineralogists. Among these may be mentioned apophyllite, which contains some fluorine in place of oxygen $K'_2Ca''_8Si_{15}\left\{ \begin{matrix} O_{38} \\ F_2 \end{matrix} \right\}16,H_2O$, pectolite $Na'_2Ca''_4Si_{16}O_{17},H_2O$, and datholite, which is a borosilicate of calcium $Ca''_4Bo'''_2Si_3O_{13},aq = Ca''Bo'''_2O_4 + 3Ca''SiO_3,H_2O$.

Apatite is a tricalcic phosphate containing fluorine, and generally chlorine. Its composition may be expressed by the formula $Ca''_3(PO_4)_2,(Ca''\begin{smallmatrix} F \\ Cl \end{smallmatrix})$. It crystallises in six-sided prisms or tables belonging to the hexagonal system. Sometimes the prisms are terminated by a six-sided prism-like quartz. The crystals, especially American specimens, are often of considerable size. They are white, grey, greenish-grey, green, wine yellow, and red; generally opaque, sometimes sub-transparent; is softer than felspar, and harder than fluor-spar. Its density 3·17 to 3·25. It also occurs massive, of a yellowish-white, or oil-green. One of the massive varieties is named *phosphorite*, because it becomes phosphorescent when rubbed. At one time phosphorus was not suspected to exist in any minerals; even Berzelius did not know of its existence in apatite, which received its name from ἀπατάειν, to deceive, on account of the mistakes of the earlier mineralogists regarding its composition. Its general diffusion in rocks was first shown by Fownes and Sullivan; since then apatite has been found to be one of the most widely diffused minerals, and to possess considerable lithological importance. Von Richthofen has recently found from 0·4 to 1·12 per cent of phosphoric acid in melaphyrs, or from about 1 to 3 per cent of apatite. Crystals of apatite occur as endomorphs in a great many minerals, especially in augite, hornblende, mica, sanidin, nepheline, etc.

CHAPTER IV.

ON THE ORIGIN, CLASSIFICATION, AND DETERMINATION OF ROCKS.

A ROCK is a mass of mineral matter consisting of many particles, either of one species of mineral, or of two or more species of minerals, or of fragments of such particles, which may or may not resemble each other either in size, form, or composition. A rock does not necessarily possess any regular symmetry of form in the external shape of the mass. Geologists are accustomed also to include under the term rock all considerable accumulations of mineral matter, whether they be hard or soft, compacted or incoherent. In this sense soft clay, loam, or loose sand, may be called "a rock."

In order to apply mineralogy to geological research we must study the genetic relations of minerals—that is to say, we must endeavour to discover their modes of production, and the circumstances which were necessary, or conducive, to their appearance in the positions and in the combinations in which we now find them. In the previous chapter some account has been given of the minerals which enter most abundantly into the composition of rocks. It is hoped that the foregoing abstract of a part of chemistry and mineralogy will enable the student to reason, to some extent, on the origin of rocks, and to draw certain conclusions as regards the relations of those mineral constituents which are essential to their existence—those which so far enter into their mass as to make them essentially what they are, and the abstraction of which would make them something different.*

* There is as yet no good English treatise on Petrography, or the classification and description of rocks—a want which it is to be hoped will be supplied at no very distant date by Mr. David Forbes. The following list will guide the student to the general literature of this subject:—

1. *Lehrbuch der Petrographie.* F. Zirkel. 2 vols. 1866. [This is the best work on Petrography yet published, though, owing to the rapid advances which are now being made in this branch of science, it is even now in some respects antiquated.]
2. *Lehrbuch der Geognosie.* Naumann. Vol. i. 1858.
3. *Classification der Felsarten.* F. Senft. 1857.
4. *Lehrbuch der Mineralien-und Felsartenkunde.* F. Senft. 1869.
5. *Rocks Classified and Described.* B. Cotta. (Translated by Laurence.) 1866.
6. *Die Krystallinischen Felsgemengtheile.* F. Senft. 1868.
7. *Chemical Geology.* Bischoff. (Translated for Cavendish Society.) 3 vols.
8. *Histoire des Progrès de la Géologie.* D'Archiac. Vol. iii., last chapter.

Crystallisation.—One of the most obvious properties of minerals is their crystallisation. All crystals are built up by the successive external addition of minute crystalline particles of like forms. It is clear, then, that these particles must have been free to move and arrange themselves; in other words, they must have been in a *fluid* or *nearly fluid* state. But this fluidity may have been the result either of *solution* in water or other liquids, or of *fusion* by heat. Whenever, then, we find a crystal, or a mineral particle that has an internal crystalline structure, we may feel assured that this structure has been produced either by *solution* or *fusion;* in other words, that the crystal has been either *dissolved* or *melted*. But if this be true as regards individual crystals, or crystalline particles, it must also be true of rocks that are made up of such crystals or such particles. Some minerals, as, for instance, calcite or carbonate of lime, are readily soluble in water containing carbonic acid gas; if, therefore, we meet with a rock composed of crystalline particles of carbonate of lime, we should naturally suppose that it had once been dissolved in acidulous water and consolidated from that solution. The solid acid silica is likewise soluble in water containing carbonic acid gas and other substances, and also in water at a high temperature.* We can, therefore, easily understand the deposition of crystals of quartz from aqueous solutions. For the production of many silicates, however (as, for instance, the artificial silicates, slag and glass), fusion by heat is necessary. Most of the natural silicates are practically insoluble in water, or in any other fluids which are found abundantly in nature. When, then, we meet with rocks composed altogether of crystals, or crystalline particles, of such silicates, we naturally conclude that those rocks were once in a state of fusion from heat.

But in each of these cases there are gradations from rocks in which the crystalline particles are large and distinct, through others where they become less and less till they are only discernible with a lens, into some which appear quite compact and homogeneous. This gradation teaches us that what is true of the crystalline rocks may also be true of compact rocks of the same mineral composition, and that, therefore, crystalline and compact limestone, quartz crystals, vein quartz, and compact flint, may equally have been dissolved in water, and crystal-

9. *Essay on Comparative Petrology*. J. Durocher. (Translated in Dr. Haughton's *Manual of Geology*.)

10. *Elements der Petrographie*. A. Kenngott. 1868.

There are in German and French literature (sparingly in our own) many memoirs and descriptions of special rocks or families of rocks. References to some of the more important of these will be given in the following pages, but for fuller particulars the student should consult the manuals of Zirkel or Cotta.

* Mr. Jeffreys showed (*Reports*, Brit. Assoc., vol. x.) that the vapour of water, at a temperature above that necessary to melt iron, dissolved silica, even attacking compact undivided minerals; and that a jet of such steam containing dissolved silica deposited a *snow* of quartz crystals as it cooled on escaping from the vessel.

line and compact silicates have equally been melted by heat. In the latter case the artificial silicate glass again assists us, since the very same mass which, if cooled rapidly, will form a perfectly homogeneous transparent glass, will, if allowed to cool more slowly, become opaque, and stony, and ultimately begin to granulate, that is, its constituents will form distinct crystalline grains in the mass.

Chemically-formed Rocks.—Many rocks, then, have been chemically formed, that is, have consolidated from fusion or solution in obedience to chemical laws. Those that have become consolidated from fusion we may call Igneous rocks; those that have consolidated from solution, Aqueous rocks.

Chemically-formed Aqueous rocks may be *crystalline* or *compact* in texture.

Chemically-formed Igneous rocks may be *crystalline*, *compact*, or *glassy* in texture.

Both kinds may have occasionally *concretionary*, *nodular*, *sparry*, *fibrous*, or other textures, according to local modifying circumstances; and some of these textures may be produced by chemical action in other rocks that were not originally of chemical formation.

In most crystalline rocks, the whole mass seems to have become consolidated so nearly at the same time, that no one mineral was able to form everywhere perfect crystals. The growth of each crystal appears to have been hindered by that of its neighbours, the whole being locked together into a congeries of mutually embedded imperfect crystalline particles. It is this which gives strength and firmness to the rock. If each particle were a perfect crystal, merely adhering by its facets to its neighbours, the rock would be apt to fall into a mere crystalline sand. This actually happens occasionally in some magnesian limestones.

In all crystalline rocks, however, whether aqueous or igneous, the crystalline particles, although not perfect crystals, have yet some faces and angles of perfect crystals, being evidently formed in the position where we now find them. They are *innate* crystalline granules. Loaf-sugar, sugar-candy, crystallised alum, are familiar examples of this structure, and will serve to explain what is meant by the *innate* crystalline structure of marble or of granite.

Mechanically-formed Rocks.—In examining the mineral composition of rocks, however, we should soon become aware of another essential difference in them. We should find many rocks the particles of which were distinct, but not at all crystalline; or if crystalline internally, their external form would not be regular like a crystal, but exhibit evident marks of mechanical fracture and attrition. The particles of these rocks would not be mutually embedded like those of chemical rocks, and would evidently not have *grown* where we now find them, but have

been brought together from some external source, and adhere to each other, either from having been squeezed together by pressure, or because they were cemented by some other substance. The very form of these particles would show that they are fragments of other pre-existing rocks, and have been broken off some parent mass, and worn by the action of moving water. This derivative origin and water-worn form are very obvious with respect to such of these rocks as consist of *pebbles*, or rounded fragments of other rocks, compacted together in *sand*, which is clearly the result of an abrading process. In many cases the very rock from some part of which the pebbles were derived can be pointed out; in other cases the fact of mechanical transport is obvious, though the original site of the pebbles may be unknown. From those cases where the individual constituents of the rock are large and their form distinctly visible, there is every gradation through those where they become less and less, till at length we meet with some in which the particles are not discernible by the lens. We have, then, compact derivative rocks, just as we have compact chemical ones.

To all such derivative rocks we may assign the term Mechanical, as showing that their materials have been mechanically procured and transported to their present sites. The machinery employed in this transportation must clearly be either currents of water or currents of air, and the mechanical rocks, therefore, must be all either Aqueous or Aerial rocks, the latter being very few and unimportant compared with the former. Even Igneous rocks, which must in themselves be purely chemical compounds, may have their mechanical accompaniments, as the ashes, cinders, and fragments blown from the mouths of volcanoes, and these may be compacted into solid rocks, whether they fall on land or into water.

Organically-formed Rocks.—There is yet another source from which some rocks are derived, since they are found to be wholly, or almost wholly, composed of fragments of animals or plants. These rocks may be termed Organic, in the sense of organically-derived rocks. The portions of the plants or animals may be either little altered from their original condition, or very much altered and altogether mineralised. In the first case, they are allied to the mechanical; in the latter, to the chemical rocks.

As, moreover, chemical precipitates are liable to be adulterated by mechanical impurities, and mechanical deposits to be impregnated with chemically-acting liquids or gases, and as both mechanical admixtures and chemical actions and reactions may play a part in the formation of rocks made of organic materials, we can easily see how all three classes of rocks may occasionally be mingled together and pass into each other, and how many aqueous rocks may have been formed by the union of two or of the three agencies, and appear to belong to one or the

other class, according to the point of view from which we observe them.

We have now arrived, then, at the conclusion that different rocks had an aqueous, an igneous, or an organic origin, solely from the consideration of the nature of the mineral particles composing them. This conclusion, however, by no means depends entirely on such considerations. The Aqueous rocks are known to be so, not only from their being composed of soluble minerals, or of minerals that have been water-worn, or of parts of plants and animals that have either lived in water or been carried down into it, but also because their materials are arranged in regular layers, beds, or *strata*, obviously the result of their having been *strewn* over the bottom of the seas, lakes, or rivers in which they were deposited. They are hence often called **Sedimentary** and **Stratified Rocks.**

The Igneous Rocks, on the other hand, are known to be such, not only from their consisting of silicates which could only be formed during fusion, but also from the absence of that regular stratification which is more or less characteristic of all rocks deposited in water. If they have anything resembling stratification, it is of that irregular kind which streams of lava possess as they flow down the flanks of volcanoes or over gently sloping ground. Many of them, indeed, are just such rocks as we see poured forth from the mouths of volcanoes in the state of molten lava. Even those which least resemble actual lava in mineral composition are often found to be *intrusive*, that is, to have been injected, either as great masses, or as veins and tortuous strings, into the body of other rocks, or else to have cut through these rocks in wall-like sheets called "dykes," just as lava cuts through rocks in the neighbourhood or in the heart of volcanoes. We cannot conceive the possibility of one aqueous rock being, at the time of its formation, intruded into or thrust through another,* since they are all formed by the tranquil *deposition* of sediment coming to rest at the bottom of some water. Intrusive rocks, therefore, must be of igneous origin. They are known as **Unstratified** or **Eruptive.**

In many cases these intruded masses have exerted such an influence as would be produced by great heat on the rock with which they came in contact. The neighbouring rocks have, in fact, been burnt or baked. This change, together with the consideration of the chemical actions and reactions that may be set up in the mass of rocks by the percolation of various fluids or gases, and the mechanical or chemical forces that may be brought into play by the action of pressure and other agencies,

* It is not necessary to take any note here of such exceptional cases as those in which, by the pressure of large bodies of ice, masses of soft strata may be contorted and squeezed into each other.

naturally disposes us to ask the question, Whether many rocks as we now see them may not be in a very different state from that in which they were originally formed? We should, on investigation, find reason to answer this question in the affirmative, and introduce another class under Sir C. Lyell's term, **Metamorphic** (or transformed) rocks. *Metamorphism*, as this change or transformation is called, is much more general than is commonly recognised. Not only Aqueous, but Igneous rocks, and their mechanically-formed accompaniments, have been metamorphosed into more crystalline rocks than they were originally. Both Aqueous and Igneous rocks have also been so acted on by mere chemical agencies as to exhibit nodular, concretionary, crystalline, fibrous, veined, or other arrangements of their component ingredients, either in parts or in the whole of their mass. Mechanical pressure has also imparted an entirely new structure to some rocks.

Four great Classes of Rocks.—We may then class all rocks whatever under the four great heads of Igneous, Aqueous, Aerial, and Metamorphic, according to the nature of the agencies by which they have been brought into their present state and position.

The **Igneous** are all chemically-formed rocks, but some of them have their mechanical accompaniments.

The **Aqueous** rocks are either chemical, mechanical, or organic, those of mechanical origin being far the most abundant.

The **Aerial** are all mechanical, and are of comparatively small importance.

The **Metamorphic** have been altered from their first condition, sometimes retaining their original structure and composition, and sometimes having these characters replaced by others, to be afterwards described.

Composition, Texture, and Structure of Rocks.—These terms are used in the following senses in this work :—

Composition refers to the mineral substances of which a rock is composed.

Texture is the grain or manner of arrangement of the component ingredients of a rock. Thus we find some rocks *granular*, others *crystalline*, or *compact* (or *crypto-crystalline*), or *glassy*, or *earthy*. Some are *porphyritic*, others *amygdaloidal*, others *vesicular*, others *schistose*—terms which will be afterwards explained. It may be remarked, however, that some differences of texture, such as the *vesicular*, become occasionally so exaggerated that they are then more properly regarded as differences of structure. Texture relates to the minuter parts of the arrangement of rocks, and can be determined from hand specimens.

Structure is the manner in which the individual particles, whatever be their texture or minuter relations to each other, are built up into a rock-mass. The structure of some rocks is *massive*, in others it is

bedded, or *amorphous*, or *jointed*, or *columnar*, or *slaggy*, or *slaty*. But as some of these structural arrangements affect even the minutest particles of the rock, Structure is occasionally found to pass into what is more usually denominated Texture. On the whole, however, Structure may be regarded as referring to the larger features of the arrangement of a rock, and can only be properly examined in cliffs, ravines, hill-sides, or in artificial openings of sufficient size, such as quarries and railway cuttings. This part of our subject falls to be treated in Section II.—Petrology.

Determination of Rocks.—In examining any specimen of rock, in order to determine to which of these classes it belongs, we proceed in the following way:—Having provided a chipping-hammer, a pocket-lens, a knife, and a small bottle of dilute hydrochloric or other mineral acid, the first thing is to form, by chipping, two fresh surfaces on the specimen, as nearly as possible at right angles to each other. These surfaces are to be carefully examined, in order to determine the texture of the rock.

Compact Rocks.—If the rock be quite compact, so that no crystals or grains be apparent even with the lens, it should be scratched with the knife. If it scratch readily, it is either an aqueous rock or a very much decomposed igneous one. If it requires some force to make any impression on it, but can be scratched when that force is exerted, it is probably a compact igneous rock; if, on the other hand, it be merely marked by the steel of the knife, as if by a hard lead pencil, it is then probably a purely siliceous rock, either flint, chert, or some other form of quartz. In that case it will be of aqueous origin, but probably either part of a vein, or a nodule, or concretion formed in a rock rather than a rock itself. If a compact rock be easily scratched, it should be tried with a little dilute acid, and if it effervesce freely it may at once be set down as limestone; if it effervesce slowly it may be a magnesian limestone; and if it do not effervesce at all it may either be gypsum or a decomposed rock.

Granular Rocks.—If the rock be granular, it must first be determined whether the grains be *innate* crystalline particles, or water-worn like grains of sand. If its texture be coarse, there will not be much difficulty in this determination. Any distinctly water-worn and rounded grain or pebble included in the rock, will at once decide the rock to be of aqueous origin. Sometimes the grains may consist of broken crystals, very little, if at all, water-worn, when it might be mistaken for a crystalline igneous rock. If, however, those broken crystals be all, or nearly all, fragments of quartz, great doubt would arise as to the correctness of that conclusion, and careful search will often disclose some grain distinctly rounded, or some little fragment which has obviously acquired its present form by mechanical fracture or attrition, proving it to be of aqueous origin. Some varieties of igneous rock enclose small globules or blebs of crystalline quartz, looking so like pebbles that they might lead the observer astray. Regular alternations of layers, slightly different in colour and texture, form strong, but not absolutely conclusive evidence in favour of the rock being a stratified or sedimentary, and therefore an aqueous one.

Crystalline or Crystalline-granular Rocks.—If, on the contrary, the rock be distinctly composed of innate crystalline particles, the point to determine will be whether those consist of carbonates or sulphates, on the one hand, or silicates on the other. If of either of the two former, it may be set down at once as an aqueous rock, if of the latter, as igneous. To determine this point, the knife should be first used—if the rock be easily scratched it is almost certainly one of the two former, if very easily scratched and the scratched part do not at all

effervesce with acids, it is probably gypsum. If the scratched part instantly boil up when acid is applied to it, it is certainly some kind of limestone. If it effervesce slowly, and have a pearly lustre and gritty feel, it is probably magnesian limestone.

If the crystalline particles be neither carbonates nor sulphates they will be silicates, and the rock an igneous one. It will then be necessary to determine the kind of igneous rock by discovering the nature of the minerals; whether in the first place there are any particles of free silica or quartz among them, and whether the remaining particles consist of hornblendic, felspathic, micaceous, or zeolitic minerals, or what mixture of these, and in what proportions. This may often be done either with the naked eye or with a lens, by recognising the minerals from their characteristic external appearance, by determining the angles formed by their facets and therefore the form of their crystals, or if neither of these methods be possible, by microscopic or chemical analyses, as described below.

Platy Rocks.—If the rock have a very decided platy structure, so that a blow with the hammer causes it to split much more readily in one direction than in any other, with a tendency to separate into many thin plates—the question which arises is, whether it be an aqueous rock formed by the successive deposition of many thin layers, or a metamorphic rock. If the former, it will probably be soft or easily broken, and the plates will run parallel to and coincide with layers of different colour or texture, or with the grain of the rock.

Metamorphic Rocks.—If, however, it be a metamorphic rock, it will probably be hard, and the plates more or less firm after separation from each other. If the faces of these plates be dull and earthy-looking, it is probably a slate or "cleaved" rock. If, however, the faces glitter with a metallic lustre, and the rock have a crystalline or semi-crystalline texture, it will then be a schistose or crystalline-schistose metamorphic rock.

The student will do well to procure, and to examine with lens, acid, knife, and hammer, specimens of the most common forms of the minerals, Quartz, Calcite, Gypsum, Felspar, Hornblende, Augite, and Mica, and endeavour to recognise them in any of the common rocks, such as Granite, Diorite, Felstone, Basalt, Limestone, Sandstone, and Gypsum, by the methods here pointed out. A little practice will enable him to do this, and he will then be able to recognise the ordinary varieties of rock which he is likely to meet with, and will know how to go about the determination of others when they occur.

Microscopic Analysis.—It often happens, however, that neither the naked eye nor a good lens will help us to get at the composition and textural arrangement of fine-grained rocks, while the rough forms of analysis mentioned in the foregoing paragraphs are equally unavailing. In such cases, much may be learnt by examining the rocks under a microscope. For this purpose a thin slice of any rock which it is proposed to examine is taken and ground smooth, and polished on one side. The polished surface is then securely fastened with Canada balsam to a piece of plate-glass, and the other side is ground down until the section is of the required thinness and transparency. The preparation may be covered with a plate of very thin glass mounted with balsam on the slide, care being taken to exclude all air-bells, and to remove all traces of the emery-powder and other substances used in the grinding and polishing process.

A rock-section prepared in this way enables us to ascertain with precision the manner in which the different minerals are built into each other, and often throws a flood of light on the origin of a rock, and on the subsequent changes which the rock has undergone. It furnishes an opportunity of applying the delicate analysis of polarised light, and thus reveals points of structure in the composition of a rock which could not be ascertained in any other way. Quite recently this method of research has been successfully adopted to discriminate between augite and hornblende, two minerals which it is very difficult to distinguish from each other when

they occur in minute crystals.* Microscopic analysis is as yet only in its infancy, but it promises to be of the very highest importance as an aid to geological research.†

Chemical Analysis.—While the microscope reveals to us the manner in which the different mineral ingredients of a rock are arranged with regard to each other, it does not always enable us to fix what the minerals are, nor inform us expressly of what elements these mineral ingredients are composed. If we wish to ascertain the ultimate chemical composition of a rock, we must have recourse to chemical analysis. Such an analysis, by revealing the nature and proportion of the elements in the rock, will tell us what possible combinations these elements might form, and thus indicate what minerals may be, and which cannot be, present. When chemical and microscopic analysis are combined, they furnish an exhaustive method of research.‡

* See Tschermak, *Sitzungsbericht der K. K. Akad. der Wissensch. Wien.* May 1869.

† The first account of this method of examination of mineral substances was given by Nicol, in Witham's *Fossil Vegetables*, Edinburgh, 1831, p. 45. He applied it to the investigation of fossil botany. The first application of it to the study of rocks was made by Mr. Sorby in a remarkable memoir communicated to the Geological Society of London (*Quart. Jour. Geol. Soc.* 1858, vol. xiv. p. 453). Since that memoir appeared little has been done in this country, though Mr. David Forbes has been steadily amassing materials which we hope will before long see the light. In Germany, however, microscopic analysis has been eagerly pursued by Zirkel, Tschermak, Fischer, Sandberger, Vogelsang, and many others. The student who is desirous of prosecuting this method of research should study the paper of Mr. Sorby. He will find much to guide him in the investigation of igneous rocks in Tschermak's admirable *Memoir on the Porphyry Rocks of Austria*, Vienna, 1869, especially the introductory part, pp. 1-29; also Zirkel's recent work, *Ueber die Mikroskopische Zusammensetzung der Basaltgesteine.* He should also consult a paper by Mr. David Forbes on "The Microscope in Geology," in the *Popular Science Review* for October 1867; Dr. Beale's work, *How to Work with the Microscope*, p. 179; and a paper by Mr. J. B. Jordan, "On an Apparatus for Preparing Rock-Sections, in the *Journal of the Quekett Microscopical Club* for July 1869. Mr. Jordan has invented an ingenious rock-slicing machine, which may be obtained from Messrs. Cotton and Johnson, Grafton Street, Soho, London.

‡ The chemical analysis of rocks is treated of in most of the petrographical works cited at the beginning of this chapter. See, in particular, Bischoff's *Chemical Geology*, and the essays of Durocher, Delesse, and Daubrée.

The student ought to accustom himself to the use of the blowpipe as an instrument to aid him in the determination of rocks. Much assistance may be obtained in this way. No field geologist should consider his outfit complete if it does not include a blowpipe, with the requisite reagents, and a microscope, with such portable apparatus as may suffice for supplying him with adequate means of obtaining thin sections of the rocks he is daily encountering in the field. Proper detailed chemical analysis is not possible as a rule to a geologist at work in the field, but he should apply for this assistance not unfrequently. It is much to be regretted that the chemical composition of British rocks has been so little attended to by British geologists.

CHAPTER V.

A CLASSIFICATION AND DESCRIPTION OF ROCKS.

I.—IGNEOUS ROCKS.

WE will commence our examination of rocks with the igneous rocks as those which are the most essentially original, and those indeed from which most others are either directly or indirectly derived.

Classification according to composition.—From what has been said before, it may be inferred that all igneous rocks without exception are composed of minerals which are silicates. These minerals may be said to belong to two great classes, silicates of Magnesia and silicates of Alumina, the species or varieties of each resulting from their various mixtures with silicates of potash, soda, lime, iron, manganese, etc. The silicates of Magnesia, etc., constitute the hornblendic, or pyroxenic, or augitic minerals; the silicates of Alumina, etc., forming the felspathic ones. The micaceous minerals, which we may look on as holding an intermediate place between them, are in reality of minor importance, so far as unaltered rocks are concerned.

The Felspars are the bases of all truly igneous rocks, those in which no felspar or mineral of that type is present being very few and unimportant, even if they exist at all. The Hornblendic and Augitic minerals hold the next most important place, and the volcanic and trappean rocks may be divided into two great series depending on the amount of those minerals which are mingled with the felspars. Those rocks in which Felspar alone occurs, or in which it greatly predominates, may be called the felspathic rocks; those in which the Hornblendic or Augitic minerals play a considerable part, may be called hornblendic or pyroxenic rocks.

In the purely felspathic igneous rocks, the felspar is either Orthoclase (monoclinic) and the rock is highly silicated or *acidic*, as in *felstone*, etc., or it is a triclinic or plagioclase felspar,* as in *porphyrite*. In the hornblendic or augitic rocks, the felspar is plagioclase, either Oligoclase, or some more basic variety, as Labradorite or Anorthite, and the rock is of a *basic* character.

* See *ante*, p. 76—Tschermak's Table of the Felspars.

Classification according to circumstances of formation.—To the geologist, however, the mineral composition of a rock is chiefly of importance as enabling him to determine its method of formation. It has been proposed accordingly to class the igneous rocks under two heads—the Volcanic or those which reached the surface, and the Plutonic or those which consolidated at some distance below it. But practically we often meet with rocks that it is difficult to place with certainty in either class. It is, moreover, often advisable to avoid terms that involve foregone conclusions. For these reasons it seems preferable to arrange the igneous rocks under three heads—Volcanic, Trappean, and Granitic. The middle term trappean is one of convenience only, to include some rocks that have been formed by volcanic action, some that are more essentially granitic, with many intermediate or undetermined rocks between the two. The term Granitic is also vague, because there are granites which are metamorphic rather than igneous rocks. The vagueness of these terms, however, is at present their recommendation, for the reasons given above.

Igneous rocks differ among themselves—

1st, In composition, as being made up of different minerals.

2dly, In having different textures.

3dly, In having different structures.

1. The mineralogical differences between the varieties of igneous rocks will be seen in the following systematic account of the more important of these varieties.

2. The chief varieties of texture are the *crystalline*, which is subdivided into *coarse-crystalline* and *fine-crystalline*; the *compact* or *crypto-crystalline* or *homogeneous*; the *granular*; the *glassy*; the *earthy*; the *porphyritic*; the *vesicular*; and the *amygdaloidal*.

Some differences of texture, as previously remarked, become occasionally so exaggerated that they pass into structural differences. This is particularly to be observed in some igneous rocks where on one side we have a finely-vesicular texture, on the other side a rock in which the cavities have become so large, irregular, and abundant, as wholly to alter the aspect of the mass and give it the structure of a slag or scoria.

When a rock is distinctly crystalline, so that the crystals of its mineral constituents are clearly discernible, they may be determined by simple inspection. In the compact and vitreous textures, however, the determination of the mineral constituents of a rock can only be arrived at—1st, By chemical analysis, which will enable us either to determine what minerals the elements found in such proportions would be likely to form, or to compare the analysis with that of other specimens of which the mineral constituents are known; or 2d, By microscopic analysis, whereby, using extremely thin sections of the rocks

mounted upon glass, we are enabled to examine their texture and mineralogical composition under a high magnifying power.

It is a known fact in the manufacture of glass, that the very same molten mass of silicates will form transparent glass,* opaque slag, or crystalline stone, according to circumstances. As these different conditions of texture receive different names, so may the different textures of natural substances receive different names, notwithstanding that in some cases they consist of essentially the same ingredients. As some slags become porous, or vesicular, and thus pass into cinders, so some igneous rocks likewise assume a vesicular or cindery character. When the pores or vesicles become filled with a crystalline nucleus or kernel of any mineral, either by subsequent infiltration, or during the process of consolidation, so that the dispersed crystalline patches look like almonds stuck into the mass, the rock is said to be an *amygdaloid*, or to have an *amygdaloidal* texture.

When single detached crystals are disseminated through a compact base, or large crystals through a fine-grained base, the rock is said to be *porphyritic*. When the amygdaloidal or porphyritic textures become so marked as to appear the most prominent characters of the rock, that rock has often been spoken of simply as an *amygdaloid* or a *porphyry*. As, however, these are incidental textures, common, the amygdaloidal to several, the porphyritic to all igneous rocks, this nomenclature elevates an accidental to an essential attribute ; a mistake which it is better to avoid.

3. The leading differences of structure among igneous rocks are the *bedded*, where the rocks are arranged in beds ; *amorphous*, where no bedded or other structure can be made out ; *massive*, occurring in large masses which can be broken or quarried in any direction ; *laminated*, divided into thin layers ; *jointed*, traversed by "joints" whereby the rock is separated into angular blocks ; *columnar*, divided by prismatic joints into prisms or columns ; *scoriaceous*, rough and ragged like the scoriæ of a volcano ; *slaggy*, resembling the slag of an iron-furnace. The structure of rocks will be treated in detail in succeeding chapters. The student will bear in mind the remark made in a previous paragraph, that *texture* and *structure* are in some directions found to pass into each other.

* The formation of crystals from a state of igneous fusion is in every respect analogous to what takes place when crystals are formed in water. It is simply the deposition of crystals from solution in a liquid that becomes solid at a high temperature, or the crystallisation of that liquid itself, in the same manner as when crystals are deposited from solution in water, or that water itself freezes. . . . A glass is a liquid which, on cooling, becomes more and more viscous, and at length solidifies without undergoing any sudden or definite change in physical structure. If, however, the liquid, after cooling to a certain temperature, crystallise, it undergoes a sudden and entire physical change, and the structure becomes stony.—(*Sorby on Microscopical Structure of Crystals. Geol. Journal*, vol. xiv. p. 465.)

A.—VOLCANIC ROCKS.

a. Crystalline.

These are often spoken of under the general term of Lava, though that term is more properly applied to the dark basaltic and frequently scoriaceous varieties which are emitted in streams from volcanic craters. They may be grouped under two divisions—1. The Trachytic family; 2. The Doleritic or Pyroxenic family.

Bunsen, in his memoir on the volcanic rocks of Iceland,* describes his *normal trachytic* rocks at one end of the volcanic series, and his *normal pyroxenic* rocks at the other end, with many intermediate varieties between the two. He states the following as the mean value of the composition of his two normal rocks, and shows that by analysing any intermediate variety of rock, and determining the proportion of any one of these ingredients (taking the silica as the easiest and best), the proportion of the other ingredients may be calculated, and thus may be determined the quantities of these two normal substances which have been mixed together to form the rock in question.

	Normal Trachytic.	Normal Pyroxenic.
Silica	76·67	48·47
Alumina and protoxide of iron . .	14·23	30·16
Lime	1·44	11·87
Magnesia	0·28	6·89
Potash	3·20	0·65
Soda	4·18	1·96
	100·00	100·00

The analyses given in the following descriptions of the rocks are chiefly taken from Durocher's *Essay on Comparative Petrology*.† They show the maximum and minimum of each ingredient observed by many different analysts, and give the mean composition of the rock.

I. The Trachytes, or Felspathic or Acidic Group.

The Trachytes are so called from the Greek word τραχυς, *rough*, as they commonly have a rough prickly feel to the finger. They are usually light-coloured, pale grey, or white, but sometimes dark grey or nearly black. They are composed principally of a felspar, rich in silica, such as Orthoclase, or its varieties, and not any of those in which the bases are more abundant, such as Labradorite or Anorthite.

Trachyte, properly so called, has either a fine-grained or compact texture, a

* Poggend. *Annal.*, vol. lxxxiii. p. 201 (1851).
† Translated by Haughton in his *Manual of Geology*.

harsh feel, and sometimes a cellular and scorified appearance. It varies in colour from a pale grey to dark iron-grey, and is sometimes reddish from the presence of iron. It is composed of a confused aggregation of crystals of felspar, often minute and needle-shaped, but with others larger and more distinct.

Trachyte contains	Maximum.	Minimum.	Mean.
Silica	71·0	64·0	66·5
Alumina	20·0	13·0	17·0
Potash	9·0	3·0	5·0
Soda	6·0	0·5	4·0
Lime	2·5	0·5	1·4
Magnesia . . .	2·0	0·0	1·1
Oxides of iron and manganese .	5·0	1·5	3·0
Loss by ignition . . .	2·0	0·0	1·0
			99·0

Specific gravity, maximum 2·70, minimum 2·60, mean 2·67.

Trachyte is divided into several varieties, according to the nature of its component felspar and other ingredients. *Normal trachyte*, according to the arrangement of Zirkel, is characterised by the absence of quartz and the presence of sanidin, either alone, when the rock forms *sanidin-trachyte*, or with oligoclase, when it is known as *sanidin-oligoclase-trachyte* or *Drachenfels trachyte*. *Quartz-trachyte* has a felsitic base, with crystals or grains of quartz and crystals of sanidin, and, less markedly, of oligoclase. *Domite* is the name given to a variety of trachyte found in the district of Puy de Dôme in Central France. It is a greyish-white, fine-grained, often earthy and friable rock, supposed by some to have been altered by the passage through it of hydrochloric acid. The trachytes are often highly porphyritic. Crystals of sanidin occur in them an inch or more in length, as in the well-known rock of the Drachenfels. Other minerals found in trachyte are hornblende, black-mica, augite, etc. In the neighbourhood of the Laacher See, rounded blocks of a trachytic rock, known as "Sanidin bombs," are rich in minerals, particularly in hornblende, mica, olivine, augite, titanite, haüyne, nosean, magnetic iron, leucite, and many others.

Pearlstone is composed of a number of globules, from the size of a nut to that of a grain of sand, of a vitreous, or enamelled aspect, and pearly lustre, occasionally adhering together without any paste. These sometimes lose their lustre and size, and pass into a compact stony mass, or they assume an internal radiated structure (sphaerulite). Pearlstone is found in some places to become fibrous, cellular, and spongy, and to pass gradually into obsidian, pitchstone, or pumice. Trachytic porphyry sometimes passes into pearlstone by insensible gradations, just as we shall hereafter see that felstone is sometimes porphyritic and sometimes nodular and concretionary.

Andesite; a trachytic rock, found in Chimborazo and other parts of the Andes, and also, according to Abich, in the Caucasus. It has various degrees of compactness and consistency, and has a coarse conchoidal fracture. G. Rose says it contains crystals of oligoclase and augite; Abich makes them oligoclase or albite, with hornblende and magnetic iron ore.

Clinkstone or **Phonolite** is a compact homogeneous rock, with a scaly or splintery fracture, sometimes conchoidal, of a greyish-green or ashy-grey colour, weathering white externally. It is often rendered porphyritic by scattered crystals of sanidin, but these are commonly not very distinctly separable from it, appearing only as brilliant surfaces here and there in the mass. Other mineral accessories are hornblende, nepheline, and magnetic iron, sometimes titanite and augite. Gmelin showed that phonolite consists of a part soluble in hydrochloric

acid, and another part not soluble. The soluble portion was considered to be a zeolite, and the rock was regarded as a trachyte, altered by sea-water.* More recent investigations, however, lead to the conclusion that the supposed zeolite ingredient may be nepheline. Jensch regards the Bohemian phonolite as consisting of sanidin, 53·55; nepheline, 31·76; hornblende (like arfvedsonite), 9·34; titanite, 3·67; iron pyrites, 0·04.

Clinkstone commonly splits into thin slabs, and is often so finely laminated as to be used for roofing slate. The slabs give a metallic sound when struck with the hammer, whence its name. It is sometimes perfectly columnar; the columns splitting across into slabs, which are also used as slates.

Clinkstone contains	Maximum.	Minimum.	Mean.
Silica . . .	62	54	57·7
Alumina . . .	24	17	20·6
Potash . . .	9	3	6·0
Soda . . .	14	3	7·0
Lime . . .	3·5	0	1·5
Magnesia . . .	2	0	0·5
Oxides of iron and manganese	4·5	1·5	3·5
Loss by ignition . .	3·5	1·0	3·2
			100·0

Specific gravity, mean 2·58.

Obsidian, or Volcanic Glass, is the completely vitreous condition of a trachytic rock. It commonly looks like coarse bottle glass, having a conchoidal fracture and breaking into sharply angular fragments, semi-transparent or translucent at the edges; black, brown, or greyish-green, rarely yellow, blue, or red, sometimes streaked. It is divided into *obsidian* proper, a perfect natural glass; *obsidian porphyry*, containing felspar crystals scattered through the glassy base; *sphærulitic obsidian*, containing sphærulitic granules, which have a more or less perfect internal radiated structure; *blistered obsidian*, a rock full of cavities, often drawn out in one direction, and giving thereby a kind of fissile structure to the rock. The last-named variety passes naturally into *pumice*.

Obsidian contains	Maximum.	Minimum.	Mean.
Silica . . .	78	61	71·0
Alumina . . .	19	10	13·8
Potash . . .	7	0	4·0
Soda . . .	11	0	5·2
Lime . . .	2	0	1·1
Magnesia . .	1	0	0·6
Oxides of iron and manganese	6	2	3·7
Loss by ignition . .	1·5	0	0·6
			100·0

Specific gravity, maximum 2·55, minimum 2·25, mean 2·40.

Pumice is the cellular and filamentous form of obsidian or other trachytic rock, and the same remarks as to composition will apply to it as to obsidian. It is, in fact, the froth of a lava, its porous and filamentous characters being due to the escape of steam or gaseous matter through it. Owing to this porous and vesicular character it swims on water, but its true specific gravity, when pounded, varies from 2·0 to 2·53, the mean being 2·30.

* See Abich, quoted in *D'Archiac*, vol. iii. p. 304.

Pumice contains	Maximum.	Minimum.	Mean.
Silica . . .	77·0	61·0	68·8
Alumina . .	18·0	10·0	14·0
Potash . .	6·0	1·5	3·7
Soda . . .	11·0	0·0	6·0
Lime . . .	2·0	0·0	1·1
Magnesia . .	1·0	0·0	0·6
Oxides of iron and manganese	4·5	0·5	3·2
Loss by ignition .	4·0	0·5	2·6
			100·0

Connected with the trachytes is a variety of rock possessing some of the characters of the doleritic series, and to which Abich gave the name of *Trachydolerite*. It contains oligoclase or labradorite, hornblende, augite, and a little magnetic iron. According to Zirkel,* the greater part of the rocks so named belong to the quartzless augitic andesites.

2. The Dolerites, or Pyroxenic or Basic Group.

The term *dolerite* (from Greek δολερος, deceptive) is the name given to a group of igneous rocks of a dark green or black colour, composed of a mixture of a triclinic felspar and augite (pyroxene), with magnetic or titaniferous iron and olivine. They are, as a whole, heavier than the trachytes, and are more *basic*, that is, contain a larger proportion of the heavier bases, while the trachytes are more *acidic*, or contain a larger percentage of silica. The doleritic rocks contain three principal varieties—*dolerite*, *anamesite*, and *basalt*; but they all pass into each other, and the names are indeed based more on mere differences of texture than on any essential distinctions.

Dolerite.—A crystalline-granular mixture of labradorite and augite, with some titaniferous or magnetic iron, and often containing a little carbonate of iron and carbonate of lime.† General colour, dark grey.

Dolerite contains	Maximum.	Minimum.	Mean.
Silica	55	45	51·0
Alumina	16	12	14·0
Potash	1	0	0·2
Soda	5	2	3·4
Lime	13	7	10·0
Magnesia	9	3	5·5
Oxides of iron and manganese .	18	9	14·7
Loss by ignition . . .	3	0·5	1·1
			99·9

Specific gravity, maximum 3·10, minimum 2·85, mean 2·95.

The labradorite forms white or light grey tabular crystals, the augite black columnar ones. Both can be distinguished by the naked eye, especially in the coarser varieties. The magnetic iron forms small octahedral scarcely visible

* *Lehrbuch*, ii. 147.

† Some of the Canadian dolerites abound in olivine. See Sterry Hunt: *Descriptive Catalogue of Minerals and Rocks of Canada in London Exhibition of* 1862, p. 82.

grains, which, when the rock is pounded, can be removed by the magnet. The most characteristic accessory mineral in dolerite is olivine, which occurs in minute granules of a yellowish or greenish tint, somewhat like grains of gum-arabic. Other minerals that also occur are nepheline, leucite, melanite, and occasionally hornblende. A variety from Aulgasse near Siegburg is said to contain 28 per cent of carbonates, three-fourths of that being carbonate of iron.

The varieties of dolerite are: *granular* or *ordinary*, *porphyritic*, and *amygdaloidal*.

Anamesite is a fine-grained or micro-crystalline dolerite, in which the component minerals are so intimately blended that they cannot readily be distinguished. Its colour is dark grey or greenish or brownish black. It forms the intermediate step between dolerite and basalt. Specific gravity 2·80.

Basalt is a compact, apparently homogeneous, nearly or altogether black rock, with a dull conchoidal fracture. Until recently basalt has been usually regarded as an intimate mixture of labradorite, augite, and titaniferous iron, with a frequent admixture of olivine, of a zeolitic substance, and of carbonates of lime and iron. After an elaborate series of microscopic investigations, Zirkel has lately divided basalt into three groups, according to the nature of their colourless silicate:—1st, *Felspathic basalts*, where the colourless and non-ferruginous silicate is a triclinic felspar. These are the most abundant of the basalts: they include all the British basaltic rocks. 2d, *Leucitic basalts*, where the clear silicate is leucite. 3d, *Nepheline basalts*, where nepheline takes the place of the felspar or of the leucite. Whatever be the nature of the colourless silicate, however, these three groups agree in being largely composed of augite and magnetic (or titaniferous) iron, with almost always more or less olivine. *Nepheline-dolerite* and *Leucitophyr* or *Leucite-rock* are names given to some of the more distinctly crystalline varieties where nepheline and leucite respectively occur.

According to differences of texture we have *ordinary basalt*, *porphyritic basalt*, *amygdaloidal basalt*, *slaggy basalt*, *wacke* or *earthy basalt*. Occasionally basalt, owing perhaps to rapidity of cooling, has assumed a glassy character. Under this phase it is known as *tachylite*, which is a dark green or black glass, very like pitchstone in external appearance. This substance has been found by Mr. Geikie not unfrequently as a thin crust on the sides of basalt and dolerite dykes in Scotland.*

Basalt contains	Maximum.	Minimum.	Mean.
Silica	53	42	48·0
Alumina	18	10	13·8
Potash	3	0·5	1·5
Soda	5	2	3·0
Lime	14	7	10·2
Magnesia	10	3	6·5
Oxides of iron and manganese	16	9	13·8
Loss by ignition	5	1	3·2
			100·0

Specific gravity, maximum 3·10, minimum 2·85, mean 2·96.

* Messrs. Chance of Birmingham melted the basalt of the Rowley Hills by simple heat without the addition of any foreign ingredient, and cast it into blocks and ornamental mouldings for architectural purposes. These blocks are internally stony, minutely crystalline in some parts, in others vesicular and slaggy. Portions, however, which were cast as thin slabs for roofing purposes, and allowed to cool rapidly, formed a glass undistinguishable by any external character from that of volcanic districts. Specimens may be seen in the Museums of Jermyn Street, London, and Stephen's Green, Dublin. An account of the manufacture will be found in *The Birmingham and Midland Hardware District*, a volume containing a series of Reports to the British Association in 1865.

Doleritic rocks, when they have been intruded among coal-seams or bituminous shales, usually become dull, and more or less earthy in texture, and white or pale yellow in colour. Dykes of this "white rock" trap, or "white horse," proceeding from the intrusive masses of the south Staffordshire coal-field, look sometimes like an earthy variety of felstone or porphyrite, and might, unless carefully examined, be even mistaken for sandstone or clay, except that they send threads and veins through the coal and other rocks, and alter them.* The late Mr. Henry determined the composition of a specimen of this "white rock" trap as follows :—

Silica	38·830
Alumina	13·250
Lime	3·925
Magnesia	4·180
Soda	0·971
Potash	0·422
Protox. iron	13·830
Perox. iron	4·335
Carbonic acid	9·320
Water	11·010
	100.073

The presence of so large a quantity of carbonic acid and water makes it appear very different in composition from any of the doleritic rocks just mentioned, but if we regard these two substances as of subsequent introduction by percolation, and as having entered into the composition of the rock as metamorphic agents, some of the silicates having been decomposed and converted into carbonates, and others of them becoming hydrated, there will be no difficulty in supposing the rock to have formed originally part of the doleritic mass from which the dykes proceed.

The names *dolerite-lava*, *anamesite-lava*, and *basalt-lava*, have been given to rocks having the character of dolerite, anamesite, and basalt respectively, and which have been erupted as lavas from recent volcanoes. But there is really no good line of separation between the two, so far as petrographical characters go. The affix "lava" serves to indicate that the rock is of modern date, and has been poured out at the surface as a lava ; but dolerite, anamesite, and basalt, have also been in a great many cases thrown out at the surface as true lava-streams, chiefly during the tertiary periods.

β. Fragmental.

The fragmentary materials ejected from a volcanic orifice during eruption vary in character from large blocks of lava down to the most impalpable dust. These materials often greatly surpass in bulk the mere lava streams which precede, follow, or accompany them. Their state of consolidation varies as much as the size and composition of their particles. Sometimes they remain quite loose and incoherent, sometimes form a solid stone. If after ejection they fall on the land, they may become compacted into a rock by the simple pressure of their own weight, or by becoming mixed with water either at the time of

* See a paper by Mr. D. Forbes in *Popular Science Review* for October 1867, Plate xvii. Fig. 5, and Plate xviii. Fig. 12. The coal-fields of Ayrshire present many illustrations of this feature of intrusive doleritic rocks. The coal is often rendered beautifully columnar when it comes in contact with the vein of igneous rock. See Catalogue of Geol. Survey specimens in Edinburgh Museum, p. 80.

eruption or by subsequent percolation. This water may either be the condensed vapour which escapes in enormous quantities from volcanic foci, or rain, or other water, subsequently gaining access to the volcanic detritus. The volcanic ash that fell on Herculaneum was mixed with water, and is therefore much more consolidated than that which covered Pompeii. If the materials fall in the sea, they become subject to the conditions under which all other mechanically-formed aqueous rocks are produced, and may then enclose and preserve shells, seaweeds, or other organisms.

The word "ash," often used to denote the finer débris showered out by a volcano, is not very good, since its primary meaning seems to be only "a fine powder, the residuum of combustion." A word is wanting to express all the loose materials blown out from a volcanic orifice during an eruption, no matter what their size and condition may be. We might call them perhaps "pyroclastic materials," but I have endeavoured in vain to think of an English word which should express this meaning. If the word "ash" is retained, it should be used with the requisite enlarged technical signification.

The following are the chief varieties of fragmental rocks of volcanic origin :—

Scoria is the name given to rough cinder-like fragments of lava which are ejected from a volcanic orifice. The term has reference to the external form and loose cellular structure of the stones.

Bombs are portions of liquid lava which have been thrown into the air, and have taken a more or less spherical form from their rapid rotation while cooling; they are frequently hollow.

Smaller fragments of igneous rocks thrown from a crater are loosely called **volcanic stones**, or **lapilli**.

The finer materials which are ejected and sometimes borne to vast distances from their point of emission are known as **volcanic sand, dust**, or **ashes**.

When these various fragmentary substances come to form rock-masses, the latter are distinguished by different names according to the texture of the component ingredients.

When a coarse unstratified mass of volcanic stones and rubbish is formed, it is known as a **volcanic agglomerate**. If the stones are rough and angular, and are grouped in layers, the rock becomes a **volcanic breccia**. If the stones, on the other hand, are rounded (especially if they are waterworn) and arranged in strata, they give rise to a **volcanic conglomerate**.

Small gravel-like fragments of ejected materials cemented together in a base of volcanic dust form rocks which are known as **tuff, volcanic ash, peperino, etc.**

Further subdivisions are made according to the mineral character of the included materials. Thus we have *basalt-breccia*, or *basalt-conglomerate*, where the fragments are wholly or chiefly of basalt; *trachyte-tuff*, where the rock is formed of triturated trachyte; so also *basalt-tuff*, *dolerite-tuff*, etc.

Trass (Duckstein, Tuffstein) is a term applied in the Rhine district to a compact form of pumiceous-tuff of a yellowish colour which has filled up some of the valleys to a considerable depth, and is now largely quarried as a hydraulic mortar.

B.—TRAPPEAN ROCKS.

It has been before said that this designation is adopted as a convenient one only, and for the same reason I would extend it. The word "trap" has often been considered to be strictly applicable only to hornblendic or augitic rocks.* It is derived from the Swedish *trappa*, a stair, from the terraced or step-like outline which the rocks present when they occur in considerable mass. The term, however, has often been used vaguely to designate any igneous rocks which could not be said to be distinctly granitic on the one hand, or absolutely volcanic on the other. In this vague and general sense I shall here use it, its very vagueness being its recommendation. Macculloch, indeed, says that the word is a "cloak for ignorance, which saves the trouble of investigation;" but in many cases it is obvious that to the field geologist the investigation is not possible. When he meets with six or eight varieties of rock in a single morning's work, sometimes forming part of the same continuous mass, he wants a name which shall express the characters they have in common, rather than their differences. The minute distinctions used to arrange specimens in cabinets and museums would often confuse and mislead the geologist, whose object is to discover, first of all, the time and mode of formation of the great rock-masses which he meets with.

As the volcanic rocks are divisible into two groups, the felspathic and the pyroxenic, so we may conveniently divide trappean rocks into two similar heads, felspathic and hornblendic. The former will comprise the siliceous traps, as Trachyte does the siliceous lavas, and Greenstone the more basic traps, as Dolerite includes all the more basic lavas. The blow-pipe comes here into play as a good practical means of distinguishing between the varieties of trap, as the more readily fusible varieties will almost certainly belong to the basic class rather than the siliceous.

a. Crystalline.

1. Felspathic Traps.

Under this division are included two groups of rock consisting

* Mr. Geikie in 1860 proposed to use the word trap as a general term to include all the igneous rocks of Scotland which do not fall within the limits of the granite family, excluding, however, such rocks as the hypersthene of Skye, which he regarded as probably metamorphic (*Trans. Roy. Soc. Edin.* xxii. 633). He thus included all the truly volcanic rocks, as well as many which are not found associated with undoubtedly volcanic phenomena. He is now inclined, however, to discard the term altogether, or at least to use it only as a convenient synonym for rocks of volcanic origin, from which craters and all trace of recent volcanic action have been removed. The volcanic rocks of the palæozoic, mesozoic, and older tertiary formations would thus be termed trappean. Some rocks would consequently come into both the Volcanic and Trappean divisions of the text. Dolerite, for instance, occurs both among the tertiary volcanic rocks, and, according to Mr. Geikie, among the older (or trappean) volcanic rocks of Scotland. See *post*, Melaphyre, and Chap. XIII.

essentially of felspar, but distinguished from each other by the nature of the component variety of that mineral. In one group are classed all those rocks which consist of orthoclase, and contain also an excess of free silica. This is the acidic group, and may be comprised under the general term *Felstone*. In the other group the rocks consist essentially of one or more of the more basic felspars. This is the basic group of the felspathic traps, and has received the name *Porphyrite*.

Felstone is a name taken from the German *Felstein*, and proposed by Professor Sedgwick to designate a class of igneous rocks to which many titles have been given, but which have not, till lately, been properly examined and described. Compact felspar, Petrosilex, Felsite, and Cornean, are among these names, as well as the Hornstone of some geologists, though that name has also been applied to chert, and to altered clay rocks. The Germans describe this rock under the head of Porphyry or Felsite Porphyry, thus assuming an accidental variety of structure as an essential character.* Any one who had mapped whole mountains and great districts of it, as the officers of the Geological Survey have done in Wales and Ireland, would have felt the necessity of having a name to distinguish the rock itself, whether it was compact, as it usually occurs there, or crystalline, or porphyritic.

Felstone is a compact, smooth, hard, flinty-looking rock. It is composed of an intimate mixture of orthoclase and quartz. It has two principal varieties; the pale green passing into a greenish or yellowish white, and the blue or grey varying from pale to dark grey. Both varieties weather white, the external margin being white sometimes to the depth of a line, sometimes to that of an inch or two. Some blocks that appear wholly white have a small blue patch in the centre, and the weathered part, especially that of the green variety, often exhibits ferrugineous stains, or even becomes wholly brown or rusty-looking. The green or greenish-white variety is often very translucent at the edges; the grey is commonly opaque. The fracture is generally smooth and straight, seldom conchoidal, but in some of the blue or grey varieties it is rough and splintery. It often splits into small slabs, and sometimes, especially the green kinds, into laminæ. The fragments sometimes ring with a metallic sound like clinkstone, and many so-called clinkstones (such as those of the Roche Sanadoire and Tuilliere in the Mont Dor district, and those of the Velay) are very similar in external characters to many of the felstones of Wales and Ireland.

Durocher, under the name of Petrosilex, gives the following composition of Felstone:—

	Maximum.	Minimum.	Mean.
Silica . . .	80	68	75·4
Alumina . . .	18	11	15·0
Potash . . .	6	2	3·1
Soda . . .	6	0	1·3
Lime . . .	2	0	0·8
Magnesia . . .	2·5	0	1·1
Oxides of iron and manganese	4·5	0·5	2·3
Loss by ignition . .	3·5	0	1·0
			100·0

Specific gravity, maximum 2·68, minimum 2·58, mean 2·64.

* Some German petrographers give a distinct heading to "Felstone, Felsite-rock and Felsite-schist, Petrosilex, Eurite, Hälleflinta." It would appear, however, that the Hälleflinta of Scandinavia and Felsite-schist are interstratified with Gneiss, and are therefore metamorphic rocks. See Cotta's *Rocks*, p. 220, English edition.

In many Felstones, both in North Wales and South Ireland, lines and striæ of slightly different colours, resembling lines of lamination or deposition, can be traced through the mass of the rock, sometimes straight, sometimes more or less wavy and tortuous, like the variously-hued lines and bands in a slag from an iron furnace, and resulting, probably, like them, from the motion of the mass when in a pasty condition.*

In the most smooth and compact varieties, the lens will often disclose small shining facets of crystals of felspar, and these sometimes become larger and more numerous till we reach the completely granular and crystalline felstones. Small crystals or crystalline portions of quartz also are occasionally present in most varieties. In some felstones there are small globules of glassy quartz, looking like little rolled pebbles, leaving round cavities in the rock when they are detached. I believe these to be crystalline *blebs* of quartz formed during the consolidation of the rock. Sometimes the rock becomes nodular and concretionary, the nodules varying in size from that of a pea to that of a man's fist, either scattered in a compact or powdery base, or touching each other and making up almost the whole mass of the rock. The substance of these nodules is sometimes the same as that of the base, but in some instances they are hollow, and contain crystals of quartz and other minerals, and also a soft, dark green earth. In this respect it seems to resemble the rock previously described as pearlstone, though it never has any pearly or other lustre.

The Rev. Professor Haughton has published † the following analyses of felstones, and shown by discussing the atomic proportions of their constituents that they may certainly be looked upon as mixtures of orthoclase and quartz, a conclusion which had previously been rather a suspicion than an ascertained fact. I have added the proportions of the two minerals at the foot, so as to comprise the whole in one table :—

	A	B	C	D	E	Means.
Silica . .	81·36	78·40	77·20	71·52	74·88	76·67
Alumina . .	7·86	11·32	6·54	12·24	12·00	9·99
Peroxide of iron .	3·32	0·92	5·82	3·16	3·50	3·37
Potash . .	3·09	4·83	3·69	5·65	4·77	4·40
Soda . .	2·63	3·09	3·03	3·36	2·49	2·92
Lime . .	0·99	0·45	1·81	0·84	0·34	0·88
Magnesia . .	0·45	0·48	0·60	0·39	1·28	0·64
Protoxide of iron .	...	..	...	...	0·20	0·04
Loss by ignition .	...	0·56	1·12	1·20	1·20	0·81
TOTALS .	99·70	100·05	99·81	98·36	100·66	99.72
Quartz . .	45·54	37·17	40·81	20·51	26·46	34·09
Felspar . .	54·16	62·32	56·07	76·65	73·00	64·44
TOTALS .	99·70	99·49	96·88	97·16	99·46	98·53

* See figures of some of the forms assumed by these lines in the felstones of Snowdon, drawn and described by Prof. Ramsay in the 3d vol. of the *Mems. of the Geol. Survey*, p. 123.

† In a paper On the Lower Palæozoic Rocks of the South-East of Ireland, by Professor Haughton, and J. Beete Jukes. *Trans. R. I. Academy*, vol. xxiii.

A was from Ballymurtagh in the Vale of Avoca, county Wicklow, from a depth of two

If we compare these analyses of Felstone with those previously given of Trachyte, we shall perceive their general resemblance. We may certainly say that some of the more highly silicated Trachytes would include some of the less highly silicated Felstones. There appears to be, therefore, no essential difference in composition between such varieties of Trachyte and some of the Felstones.

The most usual form of Felstone is one which is perfectly compact, sometimes as much so as porcelain. When the quartz is distinctly segregated into grains or crystals, the rock is called a quartziferous porphyry (*quartzführender porphyr, porphyre quarzifère.*) When in a ground-mass or base of compact Felstone distinct crystals of felspar lie scattered about, the rock then becomes a porphyritic Felstone, or Felstone porphyry. It not unfrequently happens that the scattered crystals of felspar are of a different colour from the base, and the rock may then be used as an ornamental marble, and is often spoken of simply as Porphyry.*

Elvan or Elvanite.—Elvan is a Cornish term for a crystalline granular mixture of quartz and orthoclase, forming veins that are either seen to proceed from granite or occur in its neighbourhood, and may thus be readily supposed to proceed from it. It is thus intimately related to the granites.

It has three varieties :—(*a.*) An equably crystalline mixture of quartz and felspar, generally fine grained. This may either be considered as a granite destitute of mica, or as a granular felstone. (*b.*) A compact felstone base with dispersed crystals, or crystalline particles of quartz, sometimes angular, sometimes rounded. This may be considered as a quartziferous felstone porphyry. (*c.*) A crystalline granular base of quartz and felspar, with dispersed crystals of either quartz or felspar.

The felspathic portion of these rocks is often earthy, probably from decomposition.

Minette consists of a felsitic base in which crystals of orthoclase and dark mica are scattered. It is thus a micaceous felstone, and bears the same relation to the acidic felspar-rocks (felstones) that mica-porphyrite does to the more basic forms (porphyrites).

Pitchstone or **Retinite** is a compact glassy rock, somewhat like solid pitch in texture, whence its name. It varies in colour from velvet-black, through various shades of dirty green and yellow, to sometimes nearly white. It has a splintery fracture; is sometimes porphyritic but not amygdaloidal. It very commonly occurs in the form of dykes or intrusive masses. The remarkable pitchstone-porphyry of the island of Eigg, in the inner Hebrides, is, according to recent re-

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or three feet in the rock, obtained by blasting, natural colour pale greyish-green, weathering white.

B From Carrickburn, county Wexford, pale greyish-green, weathers quite white, becomes in places nodular concretionary, having balls from one to three inches in diameter.

C Bonmahon, county Waterford, pale greenish-grey, stratified in some places, in others columnar, translucent on edges.

D Benaunmore, near Killarney, columnar, greenish-grey, compact with facets of felspar and globular specks of quartz.

E The rock called Pits Head, between Beddgelert and Caernarvon, North Wales, pale green, semi-translucent, with facets of felspar.

D is embedded in rocks of Old Red Sandstone, surrounded with great beds of "ash" of the same composition as itself. The others are all included in Lower or Cambro-Silurian rocks, generally associated with similar "ashes," or "felstone tuffs."

* The literal meaning of the word "porphyry" is purple, because the earliest used stones of this description had their prevailing hue of a deep red.

searches by Mr. Geikie, the remaining fragment of a *coulée* which filled up a river channel during the tertiary period.*

Durocher gives the following analysis :—

Pitchstone contains	Maximum.	Minimum.	Mean.
Silica . . .	74·0	62·0	70·6
Alumina . .	17·0	11·0	15·0
Potash . .	6·0	0·0	1·6
Soda . . .	3·0	1·5	2·4
Lime . . .	1·5	1·0	1·2
Magnesia . .	2·0	0·0	0·6
Oxides of iron and manganese	4·0	1·0	2·6
Loss by ignition .	8·5	0·0	6·0
			100·0

Specific gravity, maximum 2·36, minimum 2·31, mean 2·34.

Clinkstone or **Phonolite** is sometimes spoken of as a trappean rock. Many of the rocks so described might not come within the definition of clinkstone given before, and may be only platy, flaggy, and laminated varieties of felstone. In some parts of North Wales and of South-East Ireland great masses of felstone, several hundred feet thick, interstratified with the clay-slates, are, like them, split into slates by a true transverse slaty cleavage, and are then undistinguishable by any *external* character from slaty phonolites.

Porphyrite.—Under this term may be included those trappean rocks which consist of a base of plagioclase felspar (oligoclase), usually with crystals of the same mineral scattered through the base, and with a variable admixture of hornblende, mica, sometimes augite, and very rarely quartz. Porphyrite varies in colour, from pale grey or white through numerous shades of red, lilac, and purple, to dark-brown or even black. The dark tints are most frequent. The texture is commonly very close-grained, usually more or less porphyritic, and frequently amygdaloidal. Owing to weathering, masses of porphyrite have often a crumbling exterior, and only yield a fresh fracture at some distance from the surface. Streng gives the following analysis of a porphyrite from near Ilfeld :†

Silica	61·97
Alumina	16·27
Oxide of iron and manganese . .	7·56
Lime	1·38
Magnesia	2·71
Potash	4·04
Soda	2·55
Loss by ignition . . .	3·45
Carbonic acid	1·04
	100·97

Specific gravity, 2·66.

Zirkel divides porphyrite into three groups : 1st, *Felspar-porphyrite* or *oligoclase-porphyrite*, consisting wholly or almost wholly of felspar. 2d, *Hornblende-porphyrite*, where crystals of hornblende become conspicuous. 3d, *Mica-porphyrite*, containing plates of mica. The same author remarks that the chief eruptions of porphyrite appear to have taken place between the period of the Devonian and

* See his *Scenery of Scotland*, p. 278.

† *Zeitschr. Deutsch. Geol. Gesell.* x. (1858), 118.

Zechstein formations.* In Great Britain, however, the Devonian period was peculiarly rich in porphyrite-eruptions. The broad central valley of Scotland is traversed by long ranges of hills which are made up of the porphyrites, tuffs, and conglomerates of the Lower Old Red Sandstone,—for example, the Ochil, Sidlaw, Pentland, and Upper Nithsdale Hills. In the same region several hundred square miles are covered by terraced hills of porphyrite erupted during the earlier part of the carboniferous period. It is possible that some of the igneous rocks of the Lower Silurian series in Wales are referable to porphyrite. Rocks which appear to range between porphyrite and melaphyre occur in various parts of the carboniferous limestone districts of Ireland.

Kersanton is a form of mica-porphyrite, having a greenish or grey base, in which occur hexagonal plates of mica, and with the felspar (oligoclase) sometimes in distinct crystals.

Kersantite is also a variety of mica-porphyrite, in which a little hornblende occurs, and which is often marked by a fissile or a porphyritic texture.†

2. Greenstones or Hornblendic Traps.

Greenstone is an old name for a numerous and important class of trappean rocks, which consist essentially of a crystalline mixture of some plagioclase felspar with hornblende or augite. Such rocks abound among the palæozoic and older secondary formations. In most cases they are probably igneous rocks in the true sense of the word, and sometimes indeed of volcanic origin. But sometimes they are so associated with metamorphic products that they appear to be also due to metamorphism.

The felspar of greenstones is commonly oligoclase, but labradorite, anorthite, or some more basic variety than oligoclase, sometimes occurs. In some of the rocks which come under this head, augite or hypersthene, or some similar mineral, is substituted for hornblende. Mica, of a dark brown colour, sometimes occurs (as in some of the Wicklow greenstones) either in distinct plates, or as coating the surfaces of small crevices or those of the other crystals.

M. Delesse says that many rocks hitherto classed as greenstone contain no hornblende, their green colour being the result of the greenness of some of the felspar composing them. B. Von Cotta remarks that their green colour is often due to the presence of chlorite in small quantity and indistinct condition.

Greenstone, like felstone, becomes sometimes porphyritic, in consequence of one or other of its constituents forming distinct crystals in a compact mixture of the rest, or larger disseminated crystals, in a fine-grained crystalline base. When the greenstone is quite compact and dark coloured, it is not, perhaps, always easy to distinguish it from basalt by any external characters. On breaking open the weathered part of a greenstone and testing it with acid, it almost invariably effervesces along the inner border of the weathered portion. Many greenstones, also, even when apparently unweathered, effervesce with acids along the minute cracks and pores in the mass.

Diorite consists of a mixture of felspar (believed to be usually oligoclase) and hornblende, varying in texture from a fine-grained compact rock, in which the crystalline state of the minerals is barely discernible with a lens, to a coarsely crystalline aggregate. Its colour is generally a dull green, varying from light to

* *Petrographie*, Bd. II. p. 34.

† See a paper and analyses of some micaceous trap-rocks from Wicklow by Dr. Haughton. *Trans. R. I. Acad.* xxiii. p. 619.

dark green, sometimes almost black. In some varieties, on the other hand, where the felspar is very white and in great quantity, the rock might be described as white speckled with dark green spots. It weathers to a dull dark-coloured brown, the weathered blocks being generally massive and well rounded, and in our latitudes covered with patches of white lichen.

Durocher gives the following as the composition of Diorite :—

	Maximum.	Minimum.	Mean.
Silica . . .	60	48	53·2
Alumina . .	20	13	16·0
Potash . . .	2	0·5	1·3
Soda . . .	3	1	2·2
Lime . . .	9	3	6·3
Magnesia . .	10	2	6·0
Oxides of iron and manganese	20	10	14·0
Loss by ignition .	2	0	1·0
			100·0

Specific gravity, maximum 3·20, minimum 2·80, mean 2·95.

In some varieties of Diorite, described by Continental petrographers, free quartz occurs, and these are paralleled with the quartziferous porphyries among the orthoclase rocks. Other varieties are distinguished by abundance of mica (*micaceous diorites*) or of hornblende. The orbicular diorite of Corsica (*Napoleonite*, *Corsite* or *Corsican Granite*) is a granular compound of anorthite, hornblende, and a little quartz, having a spheroidal texture, which gives the rock the appearance of being built of an aggregate of well-rounded balls.

Diallage-Rock (*Euphotide*, *Gabbro*, *Serpentinite*, *Norite*, *Granitone*), a coarse or fine grained rock, generally of a palish green, or grey, but sometimes olive or greenish-brown colour, with sometimes a granitic, sometimes a porphyritic look. It is composed of labradorite and diallage. The labradorite is sometimes of the variety called saussurite, and the diallage of the variety called smaragdite, differences which affect only the lustre or colour of the rock.

Diallage-rock occurs in different parts of Britain associated with metamorphic rocks, as along the south coast of Ayrshire, and is probably, at least in some cases, itself metamorphic.

Diallage-rock contains	Maximum.	Minimum.	Mean.
Silica . . .	54	45	49·0
Alumina . . .	17	12	15·0
Potash . . .	1	0	0·3
Soda . . .	4	0·5	2·5
Lime . . .	14	6	9·5
Magnesia . . .	15	7	9·7
Oxides of iron and manganese	14	8	11·5
Loss by ignition . .	6	1	2·5
			100·0

Specific gravity, maximum 3·10, minimum 2·85, mean 2·95.

Hypersthene-Rock (*Hypersthenite*, *Hyperite*) is a mixture of labradorite and hypersthene, sometimes fine grained, sometimes excessively coarse, as in St. George's Bay, Newfoundland, where I have myself seen the rock; and where it consists of the two minerals in crystals as large as the fist. The hypersthene is dark brown, inclining to black, and the labradorite is green, with glancing shades

of blue and red. When fine grained, the rock resembles *Diabase* or *Aphanite* of a dark brownish-green, or a pale green, according to circumstances.

Hypersthene-rock contains	Maximum.	Minimum.	Mean.
Silica	55	48	51·8
Alumina	16	12	14·5
Potash	1	0	0·2
Soda	3	1	2·0
Lime	9	5	7·6
Magnesia	14	6	9·3
Oxides of iron and manganese	19	8	14·0
Loss by ignition	1	0	0·6
			100·0

Specific gravity, maximum, 3·10, minimum 2·85, mean, 2·95.

Hypersthene-rock is frequently associated with metamorphic rocks in such a way as to suggest that in these cases, as with diorite and diallage-rock, it may itself have a metamorphic origin.*

Melaphyre.—This name has been applied by Continental petrographers to so many different rocks that it has become a source of confusion, and its use in this country would require to be qualified with the name of the author whose definition might be employed. Senft's description of the rock is the following:—An indistinctly mixed rock, of dirty greenish-brown, or reddish-grey, or greenish black-brown, passing to a completely black colour, hard and tough in the fresh state—in which appear crystals of reddish-grey labradorite, with magnetic titaniferous iron, and commonly with some carbonate of lime, carbonate of iron, and ferruginous chlorite (delessite), sometimes in crystalline grains, sometimes compact or earthy, sometimes porphyritic or amygdaloidal. According to Naumann, it is a close-grained rock, very often amygdaloidal, and composed essentially of labradorite, with an undetermined silicate, some titaniferous iron, carbonate of lime and of iron, also occasionally crystals of augite, rubellan, and mica.† Zirkel's definition is a usually crypto-crystalline, sometimes porphyritic, and also very often amygdaloidal rock, consisting of a mixture of oligoclase and augite with magnetic iron.‡ According to Durocher, the composition of melaphyre is found by analysis to be the following:—

	Maximum.	Minimum.	Mean.
Silica	55	49	52·2
Alumina	25	18	21·6
Potash	3	0	1·5
Soda	6	2	4·0
Lime	8	4	6·2
Magnesia	5	3	4·0
Oxides of iron and manganese	12	5	9·0
Loss by ignition	3	1	1·5
			100·0

Specific gravity, maximum 2·95, minimum 2·75, mean 2·85.

It is probable that many of the dark compact heavy rocks of igneous origin, which occur among the later palæozoic rocks of Britain, come under one or other of the definitions of melaphyre. Such rocks are found in the carboniferous formations of Scotland and Ireland, and they seem to occur also among the so-called New Red Sandstone of Devonshire. If we take the composition of melaphyre to

* See *Trans. Roy. Soc. Edin.* vol. xxii. p. 633, *note*.

† *Lehrbuch*, i. 587.

‡ *Lehrbuch der Petrographie*, ii. 39.

be essentially a mixture of labradorite and augite (or an allied silicate), with titaniferous or magnetic iron, there is no radical mineralogical difference between such a rock and dolerite. Indeed, there seems now to be a growing tendency among petrographers to retain the name melaphyre as a geological term for all doleritic rocks of palæozoic age. The utility, however, of introducing stratigraphical distinctions into the naming of rocks which do not differ petrographically may be questioned. It is natural that a rock erupted in palæozoic times should have undergone, from infiltration or otherwise, more internal change than a similar rock of tertiary age; but it may be doubted whether this change (unless where carried to an extreme) necessitates a difference of name.

Diabase.—This name is given by German petrographers to a crystalline-granular mixture of labradorite (or oligoclase) and augite (or hypersthene), with chlorite, and sometimes with an impregnation of carbonate of lime. Rocks of this character occur through the Silurian, Devonian, and Carboniferous systems of Germany.* A coarse-grained diabase from near Christiania, analysed by Kjerulf,† gave the following composition:—

Silica	50·14
Alumina	16·43
Protoxyde of Iron . . .	12·79
Lime	6·49
Magnesia	4·36
Potash	1·54
Soda	4·56
Water	2·40
Carbonic acid . . .	0·36
	99·07

Specific gravity, 2·7 to 2·9.

The chloritic ingredient in diabase, as well as the occurrence of carbonate of lime, probably indicates that the rock has undergone more or less alteration. The mere occurrence of chlorite therefore seems hardly to justify the retention of a special name for rocks which do not differ essentially from many so-called melaphyres.

Aphanite is a name given to the more compact close-grained varieties of greenstone. By some authors it is restricted to the dioritic rocks, by others it is extended also to the compact diabases. Where the texture of the rock is so fine that the use of a lens does not enable us to determine the component minerals, it is difficult to distinguish between the close-grained extremes of diorite and of diabase. In such cases the term aphanite may be used as a provisional name until the true composition of the rock is ascertained. Some varieties of aphanite contain abundant grains of carbonate of lime, or carbonate of magnesia (*Calcaphanite*), in others the grains pass into larger kernels composed of felspar or of pistacite (*Variolite*). It is probable that many of such varieties should be classed with the tuffs.

Wacke.—This name is given by German petrographers to decomposed forms of basic igneous rocks, usually to members of the doleritic group. Basalt and dolerite tend to weather into a dull yellowish or brownish mass, which varies from a compact texture, giving a shining streak, down to mere loose earth.

β. Fragmental.

As the volcanic rocks consist partly of materials ejected as dust, sand, and stones, subsequently more or less consolidated, so the trappean rocks, many of which are merely volcanic rocks of older geological

* Senft, *Classification der Felsarten*, Tabel I. † *Christiania-Silurbecken*, 26 (1855).

date, have likewise such mechanically-formed masses in their series. The Fragmental Trappean Rocks are those which have resulted from the deposition and consolidation of ancient volcanic detritus. This detritus has evidently in many cases been ejected in the form of dust and gravel, with large blocks or bombs, just as similar materials are still vomited by modern volcanoes. Falling into water, and there re-arranged, the detritus has been consolidated into beds of rock, which vary in thickness from less than an inch up to several hundred feet. In other cases it is probable that the detritus has been derived from the gradual degradation (by atmospheric and aqueous agencies) of previously-formed crystalline trappean rocks. It is sometimes difficult or impossible to distinguish between these two modes of formation. Where we find a bed or series of beds composed of finely-comminuted trappean materials, with here and there a rounded bomb of some trap rock, or a large angular block of trap or of sandstone, shale, slate, limestone, or other stratified rock, we may with considerable certainty affirm that we have before us a deposit of ancient volcanic ash and stones. Where, on the other hand, we meet with a rock composed of finely-triturated trappean detritus, but with numerous well-rounded and evidently water-worn stones, we may conclude that in such a mass we see a deposit resulting from the waste of pre-existing trappean rocks, after the manner in which sandstones, shales, and conglomerates are formed.

The Fragmental Trappean Rocks are divided into the following groups :—Tuff or Trap-tuff, Trappean Breccia and Conglomerate, Trappean Agglomerate.

Tuff, Trap-tuff.*—Under this term are comprehended all the finer-grained varieties. These range in texture from a very close grain, resembling that of some of the more compact crystalline trap-rocks, up to that of a coarse gravel. The coarser varieties, when their component detritus is angular, pass into trappean-breccia; when it is rounded, into trappean-conglomerate. Trap-tuff is usually well stratified; where it is not so, but consists of a tumultuously-assorted mass of volcanic detritus, it passes into trappean-agglomerate.

Trap-tuff is subdivided according to the nature of the rock of which its base or its component fragments are composed.

Felstone-tuff.—The felstones of Wales are accompanied with various fragmental rocks. One of the characteristic varieties is a rather coarse-grained flaky rock, with little nodular grains enveloped in the flakes. It is generally of a pale green, pale grey, or white colour. It has often a soapy feel to the touch, and might be then called chlorite-schist by many persons.† The flakes may sometimes

* The term *ash* has been very generally used in England for this group of rocks. The word, however, is in several respects objectionable, and should be disused in favour of the older term in the text.

† It is evident that many of the palæozoic tuffs have undergone metamorphism, and are now considerably changed from their original condition. Some of these altered varieties are hornblendic, and pass into a kind of hornblende-slate. It is quite possible that some of the hornblende- and actinolite-schists interbedded among gneiss and other metamorphic rocks, may be altered tuffs.

be easily detached, and are then found to be translucent, and can readily be ground down into powder. Other varieties are much harder and more compact, and there is every gradation from a soft tuff into a compact felstone, hand specimens of which are undistinguishable from rocks which were undoubtedly once in a melted state. When decomposed, the tuff has often a brown or yellow rusty stain, and it is rare to find a mass of which a specimen will not effervesce slightly with acids, either on its general surface or in its minute crevices. Some varieties, even those that have most the appearance of crypto-crystalline trap, show casts of fossils, and many contain angular fragments of slate and other rocks, clearly betraying their mechanical origin. Some even contain crystals of felspar, which make the rock look like a porphyry, until closely examined, when the crystals are found to have their angles worn, and to have been more or less weathered and rounded before they were included in the base. Along with these, also, there generally occur angular or rounded fragments of felstone, slate, or other rocks, of every size up to blocks of 6 or 8 inches in diameter; the rock then becoming a trappean breccia or conglomerate, with either a hard and compact, or a loose and flaky base. Quartzose sand is sometimes mingled with this base; and there is then a passage from tuff through sandy tuff and tufaceous sandstone, into pure sandstone. In the same way calcareous matter (with abundant fossils) is sometimes mingled with the tuff, and even in such abundance that the rock passes at last into limestone. The nodular concretionary structure, which is occasionally to be seen in some of the compact or crypto-crystalline trap-rocks, likewise occurs in felstone-tuff very abundantly, and it is not always easy to determine whether the nodular rock was originally a molten trap or a tuff. The nodules vary from the size of nuts to that of the fist, but are sometimes still larger, and the whole mass of the rock made up of them.*

Porphyrite-tuff.—The porphyrites of the Old Red Sandstone and Carboniferous formations of Scotland are abundantly associated with tuffs made up of their detritus. These tuffs vary of course in character with the nature of the rock from which they have been formed. They are usually dull, granular, stratified, varying in colour from white through many shades of yellow, red, and lilac, to dark brown.

Greenstone-tuff (Diabase-tuff).—Under this term are included the tuffs which are composed mainly of a comminuted paste of some variety of the greenstones. They are usually dull and earthy in texture, often granular, passing into fine conglomerate, and have a prevailing dirty green colour.

Many examples are to be found in Ireland, in the parts examined by the Geological Survey, especially in the county Limerick,† of tuffs derived from some basic trap rocks. They vary from the finest grained, almost porcellanic-looking rock of a pale green or dull purple colour, through every gradation of texture, up to breccias and conglomerates. The fragments and pebbles in these trappean breccias are either portions of trap, or fragments of limestones, sometimes of some inches in diameter, and they form great beds, several hundred feet thick, interstratified with beds of carboniferous limestone, and surrounding bosses of trap, from which thick widely-spread sheets of trap also extend for many miles. Some of these trap-tuffs, with pebbles of carboniferous limestone, forcibly reminded me

* For descriptions of the tuffs of Wales see Professor Ramsay's memoir on N. Wales (*Mem. Geol. Surv.* vol. iii.); also, *Catalogue of Rock Specimens in Jermyn Street Museum, London*.

† See explanations to Sheets 143, 144, 153, 154 of the *Geological Survey of Ireland*, and *postea*, Chap. XIII.

Near Black Ball Head, county Cork, is a cliff of greenstone-tuff, in which crystals of hornblende, three inches wide, have been seen. They are dull and worn externally, but internally quite bright and glistening.

of the volcanic ashes in Darnley and Murray Islands, in Torres Straits, in which pebbles of coral limestone were included together with pebbles of the lava-flows of which the islands were partly composed.

Some of the greenstone-tuffs and breccias in the carboniferous rocks of Limerick, as also in the older Silurian rocks of the county Wicklow, contain fragments of vesicular greenstone such as is not known *in situ* anywhere in the neighbourhood. It is probable that these scoriaceous fragments are derived from the upper surface of the old trap-stream when first poured out, that upper surface having been destroyed and swept away before the lower part of the trap was covered by the deposition of the aqueous rock over it. These scoriaceous pebbles are interesting, therefore, as the only relics of a former vesicular and almost pumiceous covering, which would assimilate the old trappean flows with those of recent volcanoes.*

Throughout the carboniferous formation of the midland valley of Scotland, there occurs a vast quantity of trap-tuff interstratified with the ordinary sedimentary rocks. This tuff has a prevalent greenish colour, and is made up of a paste of abraded doleritic (melaphyre) rocks, with fragments of these rocks, and of shale, sandstone, limestone, etc. It is usually well stratified. In texture it varies from a fine-grained rock like a compact sandstone up to a coarse gravelly admixture of trappean rocks, which passes into trappean conglomerate. Rounded bombs of doleritic trap frequently occur even among the finer-grained strata. Gradations occur everywhere of these tuffs into the sandstones, shales, or limestones, lying above them. In the tuffs fossil shells and plants frequently occur, and occasionally a seam of coal is found among a series of beds of tuff. A marked feature of these rocks is the limited area over which each bed or group of beds of tuff usually extends. It appears that during the carboniferous period the midland valley of Scotland was dotted over with hundreds of little volcanic orifices, from which showers of volcanic dust and small coulées of dolerite were emitted.†

Schalstein.—German petrographical literature abounds in descriptions of this rock, which presents so many various characters in different districts that it is somewhat difficult to give one generally applicable definition. In colour it ranges through shades of grey, green, and yellow, to red and brown, but is usually variegated. It is impregnated with carbonate of lime, has a compact, earthy, or fissile texture, and contains flat pieces of clay-slate, or other rock, occasional crystals and grains of felspar, abundant roundish grains of calc-spar, which mineral occurs also in nests, and veinings through the rock.‡ According to Zirkel, some schalsteins appear to have been originally forms of greenstone-tuff subsequently altered; others to have been derived from the degradation of clay-slate.§

Another variety of trap-tuff occurs in the form of a red earth between beds of dolerite or basalt. Examples occur among the carboniferous trap-rocks of the basin of the Forth, and on a much more extensive scale among the miocene volcanic rocks of Antrim and the Inner Hebrides. Every visitor to the Giants' Causeway has noticed the horizontal red bands which there run along the face of the cliffs. These are known locally as "red ochre." They are undoubtedly beds of tuff, the result of the deposition of volcanic dust ejected during the formation of the great basaltic plateau. They consist of pinkish and yellowish trappean powder, enclosing angular fragments of minutely vesicular trap, and containing in some places

* See paper on Igneous Rocks of Arklow Head (*Journal Geol. Soc. Dub.*, vol. viii. p. 23).

† For descriptions of these tuffs see papers by Mr. Geikie in the Memoirs of the Geological Survey of Scotland; *Geology of Edinburgh*, chaps. iv.-viii.; *Geology of East Lothian*, chap. v.; also *Trans. Roy. Soc. Edin.*, vol. xxii. p. 646 *et seq.*; *Geological Magazine*, vol. i. p. 22.

‡ Zirkel, *Petrographie*, Band. ii. 536.

§ Zirkel, *loc. cit.*

concretions of red pisolitic hæmatite. In other instances they pass into a brown compact earthy clay, but they are all the contemporaneous accompaniments of the eruptions from which the basaltic flows proceeded, and the more minutely vesicular fragments they contain are the more frothy parts of those flows, either blown from the orifices and falling into the sea, or swept from their surface immediately on their first cooling.*

Trappean-Conglomerate, Trappean-Breccia.—When a rock consists of rounded fragments of one or more varieties of trap-rocks imbedded in a paste of the same materials, it is called a Trappean- (or Trap-) Conglomerate. When the fragments, instead of being round, are angular, the rock is a Trappean- (or Trap-) Breccia. Such rocks pass naturally into Trap-tuff. They occur as beds interstratified with or resting upon the crystalline traps. They may be subdivided, like the tuffs, according to the nature of the materials of which they are composed. Thus we have Greenstone-Conglomerate and Greenstone-Breccia, Felstone-Conglomerate and Breccia, Porphyrite-Conglomerate and Breccia, and so on. In some cases we can be certain that the detritus of which these rocks consist was actually ejected as loose materials from volcanic orifices, and that it fell into water and consolidated there. In other cases we have proof that the conglomerate was formed by the abrading action of waves upon exposed masses of trap-rock. It sometimes happens, however, that we cannot absolutely decide in which of these two ways a trappean-conglomerate has been formed, or whether both processes may not have been at work.

Trappean-Agglomerate (volcanic agglomerate).—This name has been given by Mr. Geikie to unstratified, pell-mell agglomerations of coarse volcanic débris, which are found occupying the pipes of old volcanic orifices. The débris consists of a coarse irregular gravelly paste, through which are abundantly scattered angular and rounded pieces of porphyrite, melaphyre, etc., with fragments of the surrounding stratified rocks. The agglomerate occurs in masses having a round or oval shape at the surface, from which they descend vertically as "necks." Many such "necks," each representing the vent of a former volcano, rise through the Scottish coal-fields, particularly in Ayrshire.†

In the preceding descriptions of the volcanic and trappean rocks such an account of them has been given as may, it is hoped, enable the student to identify the more marked varieties. It will ordinarily be sufficient for him to determine in the field whether the rock is a crystalline or fragmental one; if it is a lava, whether it be a trachyte or siliceous lava on the one hand, or a dolerite or basic lava on the other; and similarly among the traps, whether it be a felspathic trap (as felstone or porphyrite), or a basic trap or greenstone. The varieties of each class should be distinguished of course on the spot, where that is possible, but in many cases they have to be left undistinguished until the specimens come to be arranged in the cabinet of classified rocks, after they have been submitted to the more exact methods of chemical and microscopic examination which cannot be pursued in the field.

* The layers of red earth often found between two lava-flows seem to be the soil formed over the decomposed lower lava, and subsequently burnt by the heat of the upper flow.

† See Geikie, *Geol. Mag.*, vol. iii. p. 243; *Memoirs of Geol. Survey, Scotland, Explanation of Sheet* 14; *Catalogue of Rock Specimens in Edinburgh Museum*, p. 83.

C.—GRANITIC ROCKS.

It has been once or twice pointed out in the preceding pages that the volcanic and trappean rocks are readily divisible into two series, according to the relative proportions of the acid (silica), and the earthy and alkaline bases which enter into their composition. The siliceous lavas or trachytes consist of the most highly silicated felspars, and some of their varieties exhibit quartz in consequence of having more silica than could be absorbed by their basic constituents. In the siliceous traps or felstones this is always the case, and the rock consists of a mixture of highly silicated felspar, with uncombined silica or quartz. It would obviously be most unlikely that the more basic felspars, such as labradorite, should have been produced in such rocks.

In unaltered felstones the quartz, although existent, rarely becomes visible, and then appears usually in detached globular particles scattered in the mass. In the felstone and trachytic porphyries, indeed, quartz is said sometimes to occur in perfect crystals of double pyramids,* but this must be looked on as an exception to the general rule, unless in the felstones which are associated with metamorphic rocks, and have themselves been metamorphosed.

In all the granitic rocks, on the other hand, quartz is not only present, but visible, the existence of crystalline particles of quartz, intertangled with the crystalline particles of the other minerals, being their most essential character. It is, however, remarkable that quartz rarely forms perfect crystals in granite, whereas the felspathic ingredients frequently do so, and the micaceous not unfrequently. The felspars, orthoclase, albite, or oligoclase, were thus solidified previously to the quartz, an anomaly to be explained perhaps by the fact of a difference between the point of fusion and the point of solidification in the minerals, and by the protracted viscosity of the quartz. This may be owing to the slow refrigeration of the mass, allowing the highly siliceous minerals to crystallise in a magma of silica, while the more rapid cooling of the porphyries and trachytes produced a mixed felspathic paste only, in which some crystals of quartz were generated.

Granite then may be looked upon as the original rock from which the purely felspathic or highly silicated traps and lavas have proceeded directly, the differences between them being due rather to the circumstances under which they have been cooled and consolidated, than to

* Baron Richtofen, *Proceed. Imp. Geol. Inst. Vienna*, March 15, 1869, as abstracted in *Geol. Journal*, vol. xv.

any essential distinction in their ingredients. It is more a difference of texture than of composition. Granite, however, might be regarded as the original mass of even the more basic traps and lavas, if we conceive that to an original molten mass of granite a quantity of the more fusible bases was in some way added.

There is now a growing opinion among geologists that granite is in many cases a *metamorphic* rock, that is to say, that it has been formed by the *metamorphism* or alteration of a pre-existing mass of stratified rock such as sandstones and greywackes. It is here described among the igneous rocks, but reference will be made to its metamorphic relations in Chapter XII., and in the section of this Manual where Metamorphism is described.

Granite.—True Granite, in its ordinary form, is one of the most easily described and certainly recognised of all rocks. It is a fine or coarse grained crystalline aggregate of the three minerals felspar, mica, and quartz. Its name is sometimes said to be derived from its granular structure, but Jameson derives it from "*geranites*," a term used by Pliny to designate a particular kind of stone. Ordinary granite varies according to the composition of the felspar and mica composing it, according to the relative proportions of those minerals to each other and to the quartz, and according to the size of the crystals, and the state of aggregation of the several constituents.

The felspar of granite is usually orthoclase, frequently flesh-coloured, sometimes white; but oligoclase also frequently occurs having a greenish or greyish-white colour, and recognisable from the orthoclase by its *fine* parallel striations. Albite is found more rarely.* The mica of granite varies greatly in colour and lustre, the silvery white or golden yellow varieties being usually potash-mica, the brown and black varieties magnesia-mica. The quartz is commonly colourless or white, but sometimes dark-grey or brown.

The proportions of the three constituents vary indefinitely, with this limitation, that the felspar is always an essential ingredient, and never forms less than a third, rarely less than half of the mass, and generally a still larger proportion. Sometimes the mica, sometimes the quartz, becomes so minute as to be barely perceptible. The texture of the mass varies also greatly, some granites being very close and fine-grained, others largely and coarsely crystalline. The colours of the rock are generally either red, grey, or white; the first when the felspar is flesh-coloured, the latter when it is pure white, the intermediate grey tints depending chiefly on the abundance and colour of the mica, but sometimes on that of the quartz. Large and distinct crystals of felspar sometimes occur, disseminated at intervals through the mass, giving the rock a porphyritic structure. It is then called Porphyritic Granite.

In the paper before quoted † the Rev. Dr. Haughton gives a very complete account of the constitution of the largest granitic mass in the United Kingdom, that, namely, that stretches south of Dublin for a distance of seventy miles. The following is the mean of the analyses of eleven specimens from so many different parts of the chain:—

* The assertion of the presence of Albite, however, as a constituent of granite, seems often to have originated in mistake. Even in the Mourne Mountain granite, according to Dr. Haughton, it is chiefly found in drusy cavities. Oligoclase also never occurs alone, though Orthoclase often does.

† *Trans. Royal Irish Acad.*, vol. xxiii.

	Maximum.	Minimum.	Mean.
Silica . .	74·24	70·28	72·07
Alumina . .	16·68	12·64	14·81
Peroxide of iron .	3·47	1·08	2·22
Potash . .	7·92	3·95	5·11
Soda . .	3·53	0·54	2·79
Lime . .	2·84	0·67	1·63
Magnesia . .	0·53	0·00	0·33
Protoxide of iron .	0·30 *	0·00	0·00
Loss by ignition .	1·39	0·00	1·09
			100·05

Dr. Haughton shows that the granite having the above average composition consists of four minerals—orthoclase, two kinds of mica, and quartz— confusedly embedded in a felspathic paste. The felspathic paste does not assume any definite crystalline form, and, therefore, is not entitled to the name of a definite mineral. It contains nearly 4 per cent of both potash and soda, and seems to be the superfluous matter in the original mixture which remained unused, as we may say, when the other minerals formed. Having separately analysed the distinct minerals, orthoclase, white mica, and black mica, and having assumed that the felspathic paste is at all events a trisilicated felspar (which it must be from the presence of free silica in the rock), Dr. Haughton calculates the proportions of each mineral, and gets the following as the mineralogical constitution of the granite:—

Quartz	27·66
Felspar (orthoclase) . . .	52·94
Margarodite (or white mica) . .	14·18
Lepidomelane (or black mica) . .	5·27
	100·05

Having established the constitution of this great mass of granite, and shown its constancy throughout its extent, he then proceeds to examine the composition of a number of granitic bosses that protrude through the slate rocks between the main chain and the sea. These were found not only to differ in composition from the main chain granite, but to differ also among themselves, so that no two of them were exactly alike. Among nine specimens analysed from as many different localities, the percentage of silica varied from 66·6 to 80·24, that of alumina from 11·24 to 18, while in the majority of them the percentages of soda and lime were greater, and sometimes considerably greater, than those of potash. It is believed that these irregular differences resulted from the differences in the composition of the particular aqueous rocks with which the granitic masses came in contact; a portion of these rocks being supposed to have been absorbed and melted down into the granite.† In one of these detached bosses—that of the hill known as Croachan Kinshela—a specimen taken from the head of a valley as deep into the granitic mass as we could reach, showed a composition resembling that of the main chain, while another specimen from the summit of the hill nearer the original slaty envelop of the granitic mass, deviated greatly from it in composition, and contained chlorite instead of mica.‡

* In one case only.

† Such differences in the composition of the various parts of one granitic mass are also explicable on the supposition that the granite is the result of the metamorphism *in situ* of rocks differing from each other to some extent in chemical composition.

‡ *Trans. R.I.A.* vol. xxiii. p. 608, etc. See *post*, Chap. XII., "On the Granitic Rocks," for an explanation of what is referred to by the "slaty envelope."

Dr. Haughton* has subsequently described the granites of Donegal, and having analysed fifteen specimens, finds that they have the following composition :—

	Maximum.	Minimum.	Mean.
Silica . .	75·24	55·20	68·44
Alumina . .	20·00	13·36	16·02
Perox. Iron .	6.64	0·0	3·09
Protox. Iron .	2·05	0·0	0·44
Lime . .	5·08	0·79	2·49
Magnesia . .	3·66	0·07	0·88
Soda . .	4·86	2·88	3·95
Potash . .	7·32	2·0	4·46
Protox. Manganese	0·96	0·00	0·8
Water . .	1·20	0·00	0·12
			99·96

He then shows that the minerals composing the Donegal granites are quartz, orthoclase, oligoclase, black mica, white mica (chiefly in veins), and sometimes hornblende. The orthoclase is either flesh colour or white, and although it is certainly that species of felspar, it contains more lime, and is altogether more than usually basic. The oligoclase is greenish-grey, with a waxy lustre, and shows on some of its facets that minute parallel striation which is characteristic of the plagioclastic felspars. The black mica is always present, but becomes brown or green when decomposed. The white mica is rather an accidental than a constituent mineral of this granite, occurring chiefly in veins with beryl and schorl. The hornblende occurs occasionally. Besides the previously-mentioned minerals, sphene, garnet, molybdenite, and copper pyrites, also occur in the Donegal granites. Dr. Haughton, then, by a masterly application of mathematical analysis to the data he has gained from chemical and mineralogical experiments, shows the granite of Doochary Bridge to contain the constituent minerals in the following percentage :—

Quartz	30·63
Orthoclase . . .	24·33
Oligoclase . . .	41·88
Black mica . . .	3·16
	100·00

These two varieties of granite—namely, that with orthoclase only, and with white mica at least as abundant as black, and the other containing oligoclase as well as orthoclase and black mica solely, or rarely with white mica, may be taken as the two typical varieties of granite. G. Rose proposes to distinguish the latter rock by the name of *granitite*. According to Durocher, granite contains—

	Maximum.	Minimum.	Mean.
Silica . . .	78·0	66	72·8
Alumina . .	18·0	11	15·3
Potash . .	9·0	4	6·4
Soda . . .	2·5	0	1·4
Lime . . .	1·5	0	0·7
Magnesia . .	2·0	0	0·9
Oxides of iron and manganese	2·5	0·5	1·7
Loss by ignition .	1·5	0	0·8
			100·0

Specific gravity, maximum 2·73, minimum 2·60, mean 2·66.

* In a paper published in *Quart. Jour. Geol. Soc.*, vol. xviii., and another in vol. xxiv. of the *Trans. R. I. Academy*.

Many varieties of granite have been named according to the occasional presence of accidental minerals. The following are the more important :—

*Protogine** (*protogine-granite, Alpine granite*).—A rock consisting of orthoclase, oliogoclase, quartz, mica, and a variety of talc. It occurs among metamorphic rocks in the Alps.

Syenitic (or *hornblendic*) *granite*, a rock in which hornblende is added to the usual ingredients of granite. By some authors this rock is called a syenite. It forms an intermediate variety between granite and syenite.

Pegmatite, a coarse granite, full of druses, and consisting essentially of orthoclase (often in very large crystals), quartz, and large plates of silvery white mica.† It occurs in veins or layers in other granitic rocks.

Graphic granite.—This variety is distinguished by a peculiar mode in which the quartz is crystallised in the felspar, so as to produce on a cross fracture of the quartz-crystals the appearance of Hebrew writing. It is of very local occurrence.

Syenite, in its true form, is a quartziferous or granitic rock. It is named from the city of Syene, in Egypt, where it is formed of a crystalline aggregate of the four minerals, felspar, hornblende, mica, and quartz; the mica being in small and uncertain quantity. According, therefore, to the nomenclature which has been in vogue in this country, syenite differs from granite solely in the fact of its containing hornblende instead of or in addition to the mica, and may be described as a crystalline granular aggregate of felspar, hornblende, and quartz; the felspar being generally red, but sometimes white, and the rock mottled red and dark green, from the occurrence of hornblende.

The petrographers of Germany, however, give a different definition of syenite. They say it consists essentially of a mixture of orthoclase and hornblende, to which oligoclase, quartz, and mica, are occasionally added. According to this definition, syenite would differ from diorite solely in the difference in the felspathic ingredient, diorite being a mixture of oligoclase and hornblende, to which mica may also be added.

The name Syenite was first used by Pliny in reference to the rock of Syene. Werner introduced it as a scientific designation, and applied it to the rock of the Plauenscher-Grund, Dresden, which is a normal syenite according to the present German nomenclature. He afterwards classed that rock, however, as a greenstone; and on finding that the rock of Syene was not in the German sense a true Syenite, and that Rozière had met with true syenite at Mount Sinai, he proposed to change the name into Sinaite—a term which has not been generally adopted.‡

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* This rock was so called because it was supposed to be the *first formed* granite. The specimens of it which I have seen, appeared to me to be metamorphic rocks and no true granite, and the descriptions given by Naumann and Senft confirm this opinion. Dr. Haughton informs me that in all the specimens of protogine from the Alps which he has examined, the dark green mineral was not talc, but dull mica or chlorite, or some kindred mineral. I can equally affirm, that all the rocks I saw in a traverse across the Alps in 1860, which could be classed under the head of protogine, were not intrusive granites, but only beds of granitoid rock interstratified with other highly metamorphosed beds. Some granite seems to contain chlorite instead of mica, but as far as my own experience goes, it is only found on the upper or outer margin of the smaller masses or intrusive bosses of granite. The same observation may be applied to the very schorlaceous granite of Devon and Cornwall, though schorl undoubtedly occurs in small detached quantities deep in some granites.

† This is the definition of Delesse and Naumann. Haüy's pegmatite is the same as the rock called graphic-granite in the text. The word *pegmatite* is from the Greek πῆγμα, *a coagulation*.

‡ Zirkel. *Petrographie*, ii. 578.

The rock called by Durocher syenitic granite,* has the following composition:—

	Maximum.	Minimum.	Mean.
Silica . . .	72·0	64	69·0
Alumina . .	17·0	12	15·0
Potash . . .	6·0	3	4·2
Soda . . .	3·5	1	2·8
Lime . . .	4·0	1	2·2
Magnesia . .	4·0	2	2·6
Oxides of iron and manganese	5·0	2	3·2
Loss by ignition .	1·5	0	1·0
			100·0

Specific gravity, maximum 2·75, minimum 2·63, mean 2·68.

The syenite of the Plauenscher-Grund, which, as just remarked, may be taken as a type of Syenite, according to the German nomenclature, is a coarse-grained mixture of flesh-coloured orthoclase and black hornblende, containing no quartz, and with no indication of oligoclase. Its composition is as follows:†—

Silica . . .	59·83
Alumina . . .	16·85
Protoxide of iron . .	7·01
Lime . . .	4·43
Magnesia . . .	2·61
Potash . . .	6·57
Soda . . .	2·44
Water, etc. . . .	1·29
	101·03

According to G. Rose,‡ the following four varieties may be recognised among syenites:—

a. *Syenite* composed of Orthoclase and Hornblende.
b. *Syenite* composed of Orthoclase, Oligoclase, and Hornblende.
c. *Syenite* composed of Orthoclase, Oligoclase, and Green Mica.
d. *Syenite* composed of Orthoclase, Oligoclase, Hornblende and Green Mica.

II.—AQUEOUS ROCKS.

We are compelled to look upon the igneous rocks as original productions. We can only speculate, and that very vaguely, on what was the condition of their materials previously to their being placed, in a molten state, in the positions where they subsequently consolidated. In our examination of the aqueous rocks, however, we can go a step farther back, and learn, either accurately or approximately, whence the materials composing them were derived, and what was their previous condition. This is true of all aqueous rocks, whether chemically, organically, or mechanically formed. The nature of the various pro-

* The name Syenitic-granite is given by B. v. Cotta to granite containing hornblende.
† Zirkel. Poggendorff, *Ann.* cxxii. (1864), 622.
‡ *Zeitschrift der Deutsch. Geol. Gesell.* B. I. 372.

cesses whereby these rocks have been and are now formed, will be described in the subsequent section on Geological Agencies. In the meantime, we have to consider the composition and arrangement of these rocks in a lithological series. We shall commence with those which have been mechanically formed.

a. Mechanically Formed.

Conglomerate or Puddingstone.—A rock consisting of consolidated gravel or shingle, the pebbles being rounded and water-worn, and bound together by a matrix of iron (ferruginous), lime (calcareous), sand (arenaceous), or clay (argillaceous). The pebbles may consist of any substance whatever; but they are most commonly composed either of quartz, quartz-rock, or some very siliceous substance. This is partly the result of the greater abundance of siliceous over other mineral matters in the composition of rock generally; but it also arises from the greater durability of quartzose substances, and from their mode of fracture. Pure silica, or highly siliceous minerals, are not so easily dissolved by water, or by any other commonly occurring solvent, as those which contain lime or other earths and alkalies. On the other hand, quartz and quartz-rock, and similar substances, though very hard, are often rather brittle; and they break into cubical lumps, rather than into plates or slabs. These squarish lumps are soon converted by motion in water into more or less globular pebbles, and are therefore set in motion with comparative facility.

In most cases the pebbles are bedded in quartzose sand. When they consist of limestone or of trap, of slate, schist, or other rock, the rock is spoken of as calcareous or trappean conglomerate, etc. The degree of induration or consolidation in conglomerates varies greatly. Some seem to have been consolidated by simple pressure; and from some of these the pebbles may often be removed by a slight blow with the hammer, or even by the knife, the form or mould of the pebble remaining in the little film of sand which fills up all the interstices between the larger fragments. Sometimes the conglomerate has been bound or cemented together by calcareous, ferruginous, or siliceous infiltrations, the matrix in which the pebbles lie being as hard as the pebbles themselves, a blow with a hammer breaking the pebbles as easily as the rock in which they are embedded.

The size of the fragments in conglomerates varies greatly. In some rarer cases, blocks of as much as six feet in length occur; but the more ordinary sizes are from that of a man's head to that of a walnut. Below that size, the rock begins to pass into the coarser varieties of sandstone. Conglomerates, although stratified rocks, often show but faint traces of bedding, and in such cases it is only on the large scale that we can recognise their bedded character.

Breccia.—When the component fragments are angular instead of rounded the rock becomes a *breccia*. In general the traces of bedding are less distinct in this rock than in conglomerate.

Sandstone and Gritstone.—The remarks as to the usually quartzose character of conglomerates hold good also with respect to sandstones. The very process by which fragments of rock are rounded produces sand, as the waste resulting from their attrition. Pebbles themselves also are gradually ground into grains of sand. Sandstone is nothing else but sand compacted into solid stone. The grains, both of sand and sandstone, generally consist of quartz, sometimes clear and colourless, sometimes dull white, sometimes yellow, brown, red, or green. The red colours are usually the result of the covering of each little grain with peroxide of iron, which sometimes acts as a cement to the stone, serving to bind the particles together. The green colours are commonly derived from silicate of iron; and the green and red are often intermingled, in consequence of the change

of the iron from the condition of a silicate to that of a peroxide. The size of the grains varies from that of a pea to the minutest particle visible to the naked eye, many sandstones and gritstones even requiring a lens in order to distinguish the particles of which they are composed.

The materials are also various, as, along with grains of quartz, may occur grains and particles of any mineral substance whatever. Flakes and spangles of mica are rarely altogether absent; and in many sandstones they occur so abundantly, and in such regular seams, as to cause the rock surfaces to glitter, and the rock itself often to split into thin plates and slabs. These are called *micaceous sandstones*. Grains of felspar, distinguishable by their dull white, yellow, or flesh colour, and peculiar appearance, occur abundantly in some sandstones, which may then be called *felspathic sandstones*. When grains of limestone occur in any remarkable proportion, the rock may be called a *calcareous sandstone*, though this designation is more often applied to sandstones, the quartzose or other grains of which are bound together by a cement of carbonate of lime, either invisible to the eye or occurring as a network of little veins and strings of crystalline carbonate of lime running throughout the stone. Calcareous sandstones graduate into *cornstones*, and thence into good limestone. The weathered surface of a cornstone or calcareous sandstone is often curiously rotten, and of a dark brown colour, the disintegration of the rock being due to the solution and removal of the carbonate of lime, and its dark colour to the peroxidation of the iron contained in it. In other cases the surface has a fine gritty aspect, owing to the prominence of the grains of sand from which the surrounding lime has been dissolved away. *Argillaceous* or *Clayey Sandstone* is a term not often used, nor is it very often applicable, though many rocks contain various mixtures of sand and clay. In some sandstones, little flat rounded patches of clay, more or less indurated, occur. Similar little patches of clay may be seen on sandy shores, either originally deposited there in little hollows, or rolled as clay pebbles from some bed of clay. In quarrying sandstone, these clay patches are commonly called "galls" by the workmen. In highly indurated grits, they sometimes assume the form of pebbles of *slate*, though the slaty appearance may often have been acquired from the subsequent induration, and not before they were embedded in the sandstone. These patches of clay or apparent fragments of slate, sometimes give to the rock the appearance of a breccia, composed of pieces of hard slate embedded in sandstone, although the rock really was formed as a loose sand enclosing lumps of soft clay.

Itacolumite.—Some sandstones in different parts of the world when split into slabs are to a certain extent flexible without fracture, almost like a thick piece of flat cable. This variety takes its name from the mountain Itacolumi in the Brazils, and is said to derive its flexibility from plates of chlorite and mica. Specimens, however, may be seen quite flexible and without any marked appearance of micaceous minerals, but seemingly genuine unaltered quartzose sandstone.

Pseudo-crystalline Sandstone.—Among sandstones derived from hard crystalline igneous rocks, it may sometimes not be easy, at first sight, to distinguish between the sandstones and the rocks from which they are derived. If the crystals of the one, after being disintegrated, become compacted together again before their angles are much worn, and retain the lustre of some of their facets, and the sandstone or gritstone thus composed be very hard and intractable, pieces of it might easily pass for an actual igneous rock.* In most cases, however, the particles of the traprock are more or less decomposed before they enter into the composition of the sandstones; and the only mistake that could then be made between them would result from a hasty glance at the weathered surfaces of the two.

* Geologists may be deceived by such a rock, and at length discover by the appearance of distinctly rounded grains that the rock, assumed to be a trap, is in reality a sandstone.

Such *Trappean Sandstones*, or *volcanic Grits*, composed of particles derived from the decomposition of greenstones and basalts, consist principally of grains of felspar and hornblende or augite, which have commonly lost all their external crystalline appearance. Quartzose grains and mica flakes are, however, often mingled with these substances, and serve to distinguish even the most crystalline-looking varieties of such sandstones from trap-rocks. The difference between a "trappean or volcanic tuff or ash," and a "trappean or volcanic sandstone," consists in this, that the materials of the tuff were derived from an igneous outburst, and were deposited at the same time with the trap or lava from which they were derived, or immediately before or after that was poured out; whereas the trappean sandstone is merely the result of the erosion of an igneous rock at some subsequent period, when, together with the other rocks among which it lay, it became exposed to the action of moving water. In some cases, doubtless, it may happen that "trappean sandstones," or "volcanic grits," put on the appearance of trappean or volcanic tuffs; and it would then be impossible to distinguish between the two kinds of rock, and say which accompanied the igneous outburst, and which was derived from the subsequent abrasion of the cooled igneous rock. These instances, however, are more rare than they might be supposed to be.*

Consolidation of Sandstone.—Sandstone, like conglomerate, may have been consolidated either by simple pressure continued for a long period of time, by pressure combined with an elevation of temperature, by the infiltration of mineral matter in solution, or by the partial fusion or solution, and subsequent reconsolidation of some of the particles composing it, or lastly, by a combination of two or more of these actions. Some of the loose tertiary sands of the north of France, such as the Sable de Fontainebleau, and the Sable de Beauchamp, exhibit these actions in a very remarkable way. These tertiary grits are often as hard, and break with as splintery a fracture, as the grits of the oldest rocks of the British mountains. On the other hand, very ancient sandstones are sometimes quite soft. Dr. Dana says that the Potsdam sandstone of North America, which lies at the base of the Lower Silurian rocks of that country, can in some places be crumbled by the fingers,† and some of the oldest Silurian formations in the low lands of Russia are still in the state of plastic clay and friable sandstone.

Distinction between Sandstone and Gritstone.—The difference between sandstone and gritstone is a vague and indeterminate one, which must necessarily be the case when the things themselves are so various and often capricious in composition and texture. The term gritstone is perhaps most applicable to the harder sandstones, which consist most entirely of grains of quartz, most firmly compacted together by the most purely siliceous cement. Quarrymen often give the name of "grit" or "greet" to any hard siliceous stone that has a granular structure, whether the grains be large or small. The angularity of the particles cannot be taken as a character, since the rock commonly called "millstone grit" is generally composed of perfectly round grains, sometimes as large as peas, and even larger; the stone then commencing to pass into a conglomerate. Westgarth Forster alludes to the millstone grit as "a coarse-grained sandstone," and describes gritstone or poststone as a "freestone of the firmest kind . . of a very fine texture, and when broken, appearing as if composed of the finest sand;" and sandstone, as "an imperfect freestone of a coarser texture than post and not so hard," more porous, more coarse and friable, and "mouldering to sand when exposed to the wind and rain."

Glauconite or *Greensand* may be mentioned here, although it really has an organic and chemical origin rather than a mechanical one; since the green grains which give it its peculiar character are silicate of iron deposited in the cells of

* See *ante* under Trap-tuff, p. 116.

† Dana's *Manual*, p. 178.

foraminiferous shells. It occurs in rocks of all ages from the Silurian downwards.* The green grains of true glauconite have a peculiar concretionary aspect and dark green colour, by which the rock may be distinguished from an ordinary green sandstone.

Local terms for varieties of Sandstone.†—Many such terms are in use in this country. The following are among the most frequent:—

Rock is used generally to denote any hard sandstone.

Rotche, or *roche*, is generally used for a softer and more friable stone.

Rubble is rough angular gravel, either loose or compacted into stone.

Hazel is a northern term for a hard grit.

Post is a northern term for any bed of firm rock, generally sandstone.

Peldon is a South Staffordshire term for a hard, smooth, flinty grit.

Calliard, or *galliard*, is a northern term for a similar rock.

Catsbrain, the form of calcareous sandstone in which the rock is traversed by little branching veins of carbonate of lime.

Freestone is a term in general use, which is often applied to sandstone, but sometimes to limestones, and even to decomposed granite, as in the counties of Dublin and Wicklow. It means any stone which works equally *freely* in every direction, or has no tendency to split in one direction more than another.

Faikes, a common term in Scotland for a shaly or fissile sandstone.

Flagstone means a stone which splits more freely in one direction than any other, that direction being along the original lines of deposition of the rock. These stones are ordinarily sandstones, though often very argillaceous, and some flagstones are perhaps rather indurated clay in thin beds than sandstone. Thin-bedded limestones may likewise often be called flagstone.

Gradations from Sandstone into Clay.—When among the materials of a sandstone there occur any containing a notable proportion of alumina, we have the constituents for the formation of clay, and it only remains for those materials to be ground down into fine powder and mixed with water, either naturally or artificially, for clay to be produced. While all or any considerable portion of the rock remains in the form of distinct grains, we might call it an *argillaceous sandstone;* the passage from that to a sandy clay, and then to a pure clay or shale, being often an insensible one.

Clay.—Perfectly pure clay is a hydrated silicate of alumina. This is the substance known as "kaolin," or "porcelain clay," derived from the decomposi-

* Carpenter's *Foraminifera*, *Roy. Soc.* p. 10.

† The wider and more general use of such local terms may be recommended, not only as facilitating the intercourse between scientific geologists and our working brethren of the hammer, but as being often in themselves more definite and precise in their shades of meaning, as well as shorter, than our cumbrous periphrases of Latin terms. Many good, short, clear, and genuine Saxon names for natural objects, still largely used by the peasantry of different districts, have been more or less allowed to fall out of literary use, greatly to the detriment of the language. As instances we need only mention the following for forms of ground:—

Scar or *Scaur*, A long line of cliff.

Torr or *Tor*, A rocky pinnacle.

Lowe, A round bare hill—the Welsh *moel*.

Coombe, A valley—the Welsh *cwm*.

Cleugh, A roundish mountain glen, the termination surrounded by steep hills.

Strath, The alluvial flat in the bottom of a valley.

Fell, A flat-topped range of hills, whether a ridge, or the edge of a table-land.

Tarn, A lake in a cleugh.

Watershed, the *divortia aquarum*, or line of division between the sources of adjacent running streams.

tion of felspar, from which the silicates of potash, soda, etc., have been washed out. In some granitic districts, the decomposed granite yields this substance, which is carried down by water, and deposited in hollows, the quartz and mica being often left behind in the state of loose sand. The ingredients of pure porcelain clay are also sometimes derived from other rocks, as at Rostellan, in Cork Harbour, where the highly inclined bottom beds of the Carboniferous limestone afforded them in considerable abundance. The rock there is a siliceous and argillaceous limestone (though no distinct nodules or seams of chert are visible in the adjacent beds), and over one small district the lime has been almost entirely removed, leaving the silica and alumina behind in the state of a crumbling powdery mass, which was at one time rather largely exported to the English potteries. Common clay, besides being mixed in variable proportions with sand, is often largely coloured with oxide of iron, and mingled with many impurities. Any very finely divided mineral matter, which contains from ten to thirty per cent of alumina, and is consequently "plastic," or capable of retaining its shape on being moulded and pressed, would commonly be called clay. The existence of a notable quantity of argillaceous matter in a rock may be known by the earthy odour it gives out when breathed upon.

These clays have a number of varieties, of which the following are the principal:—

Pipe-clay, free from iron, white, nearly pure.

Fire-clay, nearly or quite free from iron, and from lime or alkalies, often containing carbon, which does not, however, prevent its forming bricks that will stand the heat of a furnace. It is probable that in good fire-clays the silica and alumina exist in just that definite proportion which on the application of heat would combine into a true silicate of alumina.

Shale, regularly laminated clay, more or less indurated, and splitting into thin layers along the original laminæ or planes of deposition of the rock. It was formerly called *slate-clay*, as distinguished from *clay-slate*. The colliers' and quarrymen's terms for shale are *Bind*, or *Bluebind*, *Metal*, *Plate*, *Shiver*, etc. When very fine, and containing a large proportion of carbonaceous matter, the collier calls it *Batt** or *Bass*, the geologist carbonaceous (or bituminous) shale, and the coal merchant often "slate." In Scotland the collier's term for shale is *Blaes* (*blues*), the shales being often bluish-grey; when lumpy, they are called *lipey blaes*; black soft argillaceous shales (or batts) are called "dauks;" the highly bituminous shales from which mineral oil is now so largely extracted are known as *shale* or *oil-shale*.† In the south of Ireland carbonaceous shale is called "kelve," or "pindy," and indurated slaty shale is termed "pinsill," or "pencil," as it is used often for slate pencils. "Slig or sliggeen" is also used indiscriminately for shale and slate in the south of Ireland. In Caermarthenshire the coal-measure shales, which are there highly indurated, are called "bluestone."

Clunch is a common name for a tough, more or less indurated, clay, often very sandy.

Loam is a soft and friable mixture of clay and sand, enough of the latter being present for the mass to be permeable by water, and with little power of adherence.

Marl is properly calcareous clay, which, when dry, breaks into small cubical or

* This term of "batt" is commonly applied in South Staffordshire to a lump of shaly coal, which will not continue to burn in the fire, and therefore soon becomes ash, and is consequently of little worth; the word has gone out of general use in the English language, except in composition, where it is retained in the word "brick-bat" for the broken end of a brick.

† See *post*, *sub voc.* Coal, p. 138.

dice-like fragments. The proportion of lime in a marl may vary from 10 to 60 or 70 per cent. Many clays, however, are commonly but erroneously called marls, which do not contain lime.

Shell-marl is the marl found at the bottom of an old pond or lake, obviously formed from the decomposition of lacustrine shells, some of which may often be seen in it.

Argillaceous flagstone is an indurated sandy clay or clayey sandstone, which splits naturally into thick slabs or flags.

Clay-slate is a metamorphosed clay, differing from shale in having a superinduced tendency to split into thin plates, which may or may not coincide with the original lamination of the rock. It will be more particularly described among the metamorphic rocks.

Marl-slate is a calcareous clay-slate.

Mud and *silt* are the incoherent and unconsolidated materials of some form of argillaceous rock, either clay, shale, loam, or marl, according to circumstances.

Mudstone is a name given to a fine, argillaceous, more or less sandy rock, which is not markedly fissile. It is, so to speak, a non-fissile shale. *Clay-rock* is a name sometimes given to a highly indurated mass of pure clay, not soft enough to be plastic without grinding and mixing in water, and not laminated as shale, nor cleaved as slate.

β. Chemically and Organically formed Aqueous Rocks.

Limestone may be hard or soft, compact, concretionary, or crystalline. It consists of pure carbonate of lime, or contains silica, alumina, iron, etc., either as mechanical admixtures, or as chemical deposits along with it. Different varieties of limestone occur in different localities, both geographical and geological, peculiar forms of it being often confined to particular geological formations over wide areas, so that it is much more frequently possible to say what geological formation a specimen of limestone was derived from than one of any other rock. No experienced British geologist would be likely to confound characteristic specimens of the limestones of the Silurian, Carboniferous, Oolitic, and Cretaceous formations of Britain and Western Europe; while no one could pretend to distinguish with certainty, from mere lithological characters, between the argillaceous or arenaceous rocks of those different formations.

Compact limestone is a hard, smooth, fine-grained rock, generally bluish-grey, but sometimes yellow, black, red, white, or mottled. It has either a dull earthy fracture, or a sharp, splintery, and conchoidal one. It will frequently take a polish, and when the colour is a pleasing one, is used as an ornamental marble.

Crystalline limestone may be either coarse or fine grained, varying from a rough granular rock of various colours, to a pure white, fine-grained one, resembling loaf sugar in texture. This latter variety is sometimes called *saccharoid* or *granular limestone*, sometimes *statuary marble*. The crystalline structure of limestone is either original, when it is often found that each crystal is a fragment of a fossil, or it has been superinduced by metamorphic action on a limestone formerly compact.

Chalk is a white, fine-grained limestone, sometimes quite earthy and pulverulent, sometimes rather harder and more compact, as the chalk of the north of Ireland, and some of that of the north of France.

Oolite is a limestone in which the mineral has taken the form of little spheroidal concretions, and the rock looks like the roe of a fish, from which its name, signifying *egg*, or *roe*-stone, is derived. These little concretions have several concentric coats, sometimes hollow at the centre, sometimes enclosing a minute little grain of siliceous, or calcareous, or some other mineral substance. It is commonly of a dull, yellow colour, but grey oolitic limestone is not unfrequent. Its peculiar structure gives it the character of a freestone, that can be cut with equal freedom

in any direction; whence its value as a building stone. Bath stone, Portland stone, Caen stone, are well-known examples of oolitic limestone, but the oolitic structure is by no means confined to what is known as the Oolitic formation, since many parts of the Carboniferous limestone of Ireland * are equally oolitic and highly valued as building stone, and the structure occurs even among the recent limestone of coral-reefs.

Pisolite is a variety of oolite, in which the concretions become as large as *peas*. A pisolitic limestone near Cheltenham is spoken of by the quarrymen as the "*pea grit.*" It is a structure not confined to limestone, however, as other rocks occasionally assume it, as also the ores of some metals.

Many limestones are named from their containing some peculiar variety of fossil, as *Nummulite, Clymenia, Crinoidal* limestone, and *Shell limestone* or *Muschelkalk*. Others have local names given them, as the *Calcaire grossier* of Paris, a coarse limestone, some beds of which are used for building, while others are a mass of broken shells. *Cipolino* is a granular limestone containing mica and talc; *Majolica*, a white, compact limestone; *Scaglia*, a red limestone in the Alps; *Ophicalcite* or *Serpentine limestone*, a fine-grained limestone, full of veins and nests of serpentine (ophite). Ireland especially abounds in a great variety of limestones used for ornamental marbles, such as the green serpentine-marble of Ballynahinch in Galway, the black marble of Kilkenny, the brown, red, and dove-coloured marble of Cork and Armagh; and many others less known, and some of them unworked, but equally beautiful with those that are. In Derbyshire and North Staffordshire we have a similar abundance of ornamental marbles.

Fresh-water (*lacustrine*) *limestones* have commonly a peculiarity of aspect, from which their origin may sometimes be suspected, even before examining their palæontological contents, or petrological relations. They are generally of a very smooth texture, and either dull white or pale grey, their fracture only slightly conchoidal, rarely splintery, but often soft and earthy. *Shell-marl* is a soft, white, earthy form of fresh-water limestone, formed by an aggregate of shells, and containing a variable quantity of clay.

Travertine, when massive, is generally of a yellow or brown colour, and a smooth and compact texture, but is sometimes perfectly crystalline. It is often mottled with concentric spheroidal bands of colour, from an inch to several feet in diameter.

Stalactites and *Stalagmites* are usually white or pale yellow in colour, but sometimes of a darker yellow or brown colour. They are commonly wrinkled externally in little ridges, taking the form of the successive films of water that trickled over the surface, while internally they exhibit concentric coats, each deposited by one of these films. It often happens, however, that radiating crystalline plates, some even half-an-inch in diameter, traverse these coats without obliterating them, showing that the whole has become crystalline internally, subsequently to the formation of the concentric coats.

Siliceous Limestone.—The silica diffused through the calcareous mud, of which the limestone was composed, has sometimes remained so diffused, instead of separating as nodules or layers, producing a *cherty* or *siliceous limestone*. In chalk, masses of silica (*flint*) are found abundantly in nodules and irregular aggregates. *Chert*, a mixture of silica with lime, occurs in layers and concretions in many limestones. These accretions will be described in a subsequent chapter.

Argillaceous Limestone.—Clay, or argillaceous matter, has frequently been

* The limestone in the neighbourhood of Edenderry, in County Kildare, and large parts of the Carboniferous limestone of the counties of Limerick, Tipperary, Queen's County, and Mayo, are perfectly oolitic in structure, sometimes more regularly so than the majority of the oolites belonging to that which is called the Oolitic formation.

deposited with the calcareous, producing *argillaceous limestone*, which may be known by the earthy odour given out by it when breathed upon.

Hydraulic Limestone.—Limestone containing a certain proportion of silica and alumina forms a mortar that sets under water, and is, therefore, called *hydraulic lime.* According to Gmelin it is a marly limestone, but should not contain more than 20 per cent of clay. He says, that hydraulic mortar is a pasty admixture of lime, silica, and water, which, when immersed in water, is gradually converted into silicate of lime, containing water of crystallisation, and hardens to a compound resembling zeolite.*

Carbonaceous or *Bituminous Limestone.*—Carbonaceous matter, derived either from decaying vegetables, or perhaps more frequently from the decomposing animals of whose hard parts the rock is composed, produces in like manner the *black limestones*, which are in some instances called *bituminous limestones.* Little nests of black carbonaceous matter are sometimes found in the hollows of shells buried in limestone. In some regions, as in the oil districts of Canada, the cavities of limestone are found filled with petroleum or mineral oil.

Fetid Limestone or *Stinkstein.*—The fetid smell, like that of sulphuretted hydrogen gas, given off by many limestones when struck with a hammer, is probably another result of the decomposition of animal matter, producing what is called "*fetid limestone,*" or, by the Germans, "*stinkstein.*" Some of the limestone quarries in the carboniferous limestone of Ireland may be smelt at a distance of a hundred yards when the men are at work, and in one instance the author was informed by the quarry-master that the men at work in a particular part of the quarry were sometimes quite sickened by the stench, and had to leave off work for a time.

Arenaceous Limestone or *Cornstone.*—Calcareous sandstone has already been described (p. 127), and an arenaceous limestone is very much the same thing. Sometimes, however, the calcareous matter predominates so largely over the arenaceous that the rock is fairly a limestone, and is known as *cornstone.* Some cornstones are quarried and burnt for lime, not differing in composition from a slightly siliceous-looking limestone, and being either compact or horn-like or semi-crystalline in texture.

Conglomeratic Limestone.—Some limestones contain angular or rounded fragments of other rocks, and thus become a conglomerate. In the county of Dublin some of the limestones belonging to the carboniferous formation contain fragments of trap, grit, or slate, varying in size from mere sand up to blocks of eighteen inches in diameter, and in quantity from a few dispersed pieces scattered through the limestone until they form a mere conglomerate of other materials, cemented by an almost invisible paste of calcareous matter. In the county Limerick we find, in like manner, gradations from pure limestone, containing a few chips of trap and trap-tuff, or a few layers of trappean sand, up to a calcareous brecciated tuff, consisting of such a mixture of calcareous and trappean materials that it is difficult sometimes to say whether any particular bed should be called a limestone or a trap-tuff. In other parts of the county Dublin from those above mentioned, and in the more immediate neighbourhood of the granite hills, the limestone contains fragments of granite varying in the same way as regards size and shape, but frequently quite angular, and several inches in diameter.† Flat slabs of mica-schist have since been found imbedded in the limestone of Milltown, near Dublin, by Mr. Carroll and others. In the counties of Galway and Sligo, near Oughterard and

* *Gmelin*, vol. iii., p. 380.

† These were first described by Dr. Lentaigne in a paper read before the Royal Dublin Society in 1851, and a number of specimens were sent by him to the Great Exhibition in London of that year. They were subsequently brought before the notice of the Geological Society, Dublin, by Professor Haughton.

Castlebar, at the boundary of the limestone formation, some of the crystalline crinoidal limestones become so full of angular fragments of crystalline quartz that their weathered surfaces look like a coarse quartzose sandstone. In some parts the limestone has also a well-developed oolitic structure, so that the rock may be described as a "siliceous, conglomeratic, crystalline, crinoidal, oolitic limestone." These unrounded fragments of granite and mica-schist may have been derived from the waste of pinnacles of the rock forming islets in the sea in which the limestone was deposited, or they may in some cases have been floated in the roots of trees and other vegetables, just as in the present day pebbles of hard stone, highly valued by the natives, are found in the roots of trees cast up upon the shore of archipelagoes of coral islands in the Pacific, as mentioned by Chamisso and Darwin. Mr. Godwin Austen has described the occurrence of a boulder of Scandinavian granite, with sand and a pebble of greenstone, in the chalk near Croydon, which he believes were transported by ice from northern latitudes.*

Rottenstone.—Wherever a compact siliceous limestone is weathered or decomposed by the action of the atmosphere, and the calcareous part removed, the siliceous skeleton of the rock is left, producing what is known as rottenstone. In arenaceous limestones, or calcareous sandstones or trap-tuffs, a similar dark-coloured, more or less rotten rock, is left by the weathering out and removal of the calcareous matter. In many cases where a ferruginous limestone decomposes, the calcareous parts are dissolved and removed, leaving a fine pulverulent porous mass of ochre.

Magnesian Limestone or **Dolomite.**—Carbonate of magnesia is often found in marine limestones, mingled in various proportions with the carbonate of lime. Its occurrence in small quantity frequently gives a sandy appearance and gritty feel to an otherwise smooth and compact limestone. In a true magnesian limestone or dolomite, the crystallisation and the pearly lustre are generally very distinct, though sometimes the crystals are minute. Its colour is commonly some shade of brown or yellow, occasionally tinged with red; white, grey, or black varieties, however, occur sometimes over very large areas. Dolomite is frequently full of cavities from the size of walnuts up to that of a man's head, and these are often coated with crystals of bitter-spar.† Dolomite is often quite disintegrated, and looks like a mere sand; but when examined by the lens, this apparent sand is found to consist of little detached crystals. Magnesian limestone is very variable in lithological character. It is sometimes of a powdery, earthy, and friable texture; sometimes splits into thin slabs, some of which are flexible; sometimes forms singular concretionary masses, as will be described in a following chapter. This rock appears to be in many, if not in most, cases a product of the gradual metamorphosis of ordinary limestone, carbonate of magnesia replacing carbonate of lime.‡

Gypsum occurs as a rock in various ways. It sometimes forms regular beds, sometimes irregular concretionary masses, sometimes veins and strings in the mass of other rocks. *Compact Gypsum* or *Alabaster* § is one variety; *granular, finely crystalline gypsum* another. The thin beds and the veins and strings of gypsum are commonly fibrous, the fibres being at right angles to the planes of the beds and to the walls of the veins. The gypsum of Montmartre, from which plaster of Paris is derived, is chiefly granular gypsum, each bed being composed

* *Quar. Jour. Geol. Soc.*, vol. xiv. p. 252.

† Any cavity in any rock lined with crystals of any substance is called a *drusy* cavity.

‡ This has been shown by Mr. Sorby from the microscopic examination of dolomites. See also the chemistry of dolomitisation discussed by Bischoff, vol. iii. chap. liii.

§ Alabaster is so named from Alabastron, a town of Egypt, where it was manufactured into boxes for ointment. The term "alabaster" was then applied to carbonate of lime, as well as sulphate of lime.

of many layers of little crystals, slightly differing in colour and texture, and thus assuming a regularly laminated appearance. This would lead us to suppose that this rock, which is associated with fresh-water limestones and marls, was formed by the periodical deposition of layers of small crystals of sulphate of lime at the bottom of the water.

Rock-salt commonly occurs in England and Ireland as a rudely crystalline, irregularly bedded mass, commonly stained of a dirty red by the mixture of ferruginous clay and other impurities. Perfect cubical and transparent crystals occasionally occur, and curious spheroidal bands of a white colour are sometimes observable in the roof of a salt-mine. Bed-like masses of rock-salt are often 60 or 90 feet thick, thinning out probably in all directions, and thus taking the form of large cakes. In other countries, more numerous beds occur, but not making up larger masses. In some of these the salt is perfectly pure and white; but the association of salt with gypsum, and with green, red, and variegated marls, is probably everywhere a frequent if not invariable occurrence. The connection of gypsum with rock-salt is natural and almost inevitable; but the accompaniment of red and variegated clays has not yet been explained. When it is, it will probably throw great light on the circumstances under which the rock-salt itself has been deposited. Dolomite is also often found in connection with rock-salt.

Coal is a term rather of commercial than of strictly scientific language. It is used to describe any rock which consists almost wholly of carbon, and which is capable of being employed by itself as fuel. By geologists it is usually restricted to those stratified rocks which have been formed by the fossilisation of ancient vegetation either on the places where the vegetation grew or on those into which it was drifted.* It is a word of generic application, and includes many varieties.

Coal is very commonly divided into bituminous and non-bituminous. Bitumen is rather a vague term, including several combustible substances, such as asphalt or mineral pitch, elastic bitumen or mineral caoutchouc, naphtha, petroleum, etc. These bituminous substances are all either fluids, or are readily soluble in alcohol. It is, however, impossible to dissolve any appreciable portion of coal in alcohol, which shows that it does not contain any actual bitumen, though it may contain the constituents of it. The natural and artificial bitumens are the result of the decomposition of vegetable matter, and may be extracted also from coal by subjecting it to distillation. They always contain from 7 to 9½ per cent of hydrogen, combined with carbon and oxygen. The so-called bituminous coals, then, are those in which the mineralising process has only proceeded to a certain extent, leaving a considerable proportionate amount of hydrogen and oxygen in their composition; while those called non-bituminous are those from which a greater quantity of the latter substances have been extracted, and a larger proportion of carbon left behind. If the decomposition of wood results in the formation of carbonic acid gas, which takes away both carbon and oxygen, or of carburetted hydrogen, which takes away a large proportion of carbon, the carbon in the remainder will not be in such excessive proportion, and the constituents of the resulting coal will more nearly resemble those of bitumen. In this sense they may be called bituminous coals. If, however, a large portion of the oxygen and hydrogen be extracted, either as water or in any other form, the proportion of carbon in the remainder becomes excessive compared with that in the composition of bitumen; and hence the coals may be called *non*-bituminous.

Coals vary greatly, not only in the proportions of their essential constituents —carbon, hydrogen, and oxygen—but also in the amount of earthy matter (forming ash) which has been accidentally and mechanically mingled with those constituents. The percentage of ash is sometimes as much as 35 per cent in coals

* The origin of coal is more fully treated in a subsequent chapter.

that have been regularly analysed. In poorer varieties of coal, however, such as are never brought to market, but which are occasionally used in particular localities, this percentage must be still greater; and we have in nature every gradation, from pure coal into a mere carbonaceous (commonly called bituminous) shale or "batt," which often contains enough inflammable matter to give out flame and support combustion for a time when burnt with better coals, but soon passes into a lump of ash, unaltered in form, and not retaining heat longer than a brickbat would under similar circumstances. These *batts*, shales, or slates, often accompany coal, being found not only either just above or just below it, but in it, in the form of thin seams, layers, or cakes, which are often not to be separated from it without some trouble. Just as limestone is often mingled with clay, and passes through argillaceous limestone and calcareous clay (or marl) into clay itself, so coal passes through earthy or ashy coal, and carbonaceous shale, into common shale or clay, no very hard boundary-line being to be drawn between the many minor graduating varieties of the different substances. Discarding the impure or imperfect coals, the recognisable varieties of good coal are sufficiently numerous. They may be grouped under three heads—anthracite, ordinary or pit coal, and brown coal or lignite.

Brown Coal or *Lignite* sometimes shows the structure of the plants from which it is derived but little altered from their original condition; stems with woody fibre crossing each other in all directions. "It is of a more or less dark colour, soft and mellow in consistence when freshly quarried, but becoming brittle by exposure, the fracture following the direction of the fibre of the wood. Other kinds present only occasional distinct indications of vegetable structure, and appear throughout as a stratified mass of a dark, nearly black colour, with an earthy fracture; while in some varieties the structure is still more dense, and the fracture is conchoidal." * The latter varieties, as in the case of the Bovey coal of Devonshire, are often scarcely distinguishable by any external characters from some varieties of ordinary coal.

Ordinary or *Pit Coal* has many varieties; indeed, these are often as numerous as the different seams of a coal-field, and even the different beds of a compound seam are readily distinguished from each other by the colliers, who give particular names to them; and even small blocks of these varieties can be recognised by them, and identified with the seam, or part of a seam, from which they are derived. Not only do the different beds of a compound seam present distinguishable varieties, but it sometimes happens that the very same identical layer of coal changes its character and quality in different parts of its area. Neither are these distinctions, which are only to be perceived after long practice, unimportant, since these varieties have distinct qualities, some of them being better adapted to smelting, and said to be "good furnace coal;" some of them to blacksmith's work, or "good shop coal;" others to various uses; while only a few, comparatively, are best fitted for domestic purposes, and are brought to market by the coal-merchant.†

Some idea of the number of varieties of coal may be gained from an inspection of the report of the Admiralty Coal Investigation,‡ as well as from the varying qualities of those which we are in the habit of using daily in our houses. "As many as seventy denominations of coal are said to be imported into London alone." § All these minute varieties are commonly included under four principal heads. 1. *Caking Coal* is so named from its fusing or running together in the fire, so as to form clinkers, requiring frequent stirring to prevent the whole mass being

* *Chemical Technology*, Ronalds and Richardson, vol. i. p. 32.

† See *Memoirs of Geol. Survey, South Staffordshire Coal-field*, 2d edition, p. 18.

‡ *Mems. Geolog. Survey*, vol. i.

§ Ronalds and Richardson, *Chem. Tech.*

welded together. It breaks commonly into small fragments with a short uneven fracture. The Newcastle coal, and many others from different localities, are caking coals. They leave many cinders and a dark dirty ash. 2. *Splint or Hard Coal* is well known in the Scottish coal-fields. It is not easily broken, nor is it easily kindled, though when lighted it affords a clear lasting fire. It can be got in much larger blocks than the caking coals, and is now largely used as a steam-coal. 3. "*Cherry or Soft Coal* is an abundant and beautiful variety, velvet black in colour, with a slight intermixture of grey. It has a splendid or shining resinous lustre, does not cake when heated, has a clear shaly fracture, is easily frangible, and readily catches fire." * It leaves comparatively few cinders, and its ash is white and light. It requires little stirring, and gives out a cheerful flame and heat. The Staffordshire coals principally belong to this variety. 4. *Cannel or Parrot Coal* is called cannel from its burning with a clear flame like a candle, and parrot in Scotland from its crackling or chattering when burnt. Cannel coal varies much in appearance, from a dull earthy to a brilliant shiny and waxy lustre. It is always compact, and does not soil the fingers. Its fracture is sometimes shaly, sometimes conchoidal. The bright shining varieties often burn away like wood, leaving scarcely any cinders and only a little white ash. The duller and more earthy kinds leave a white ash, retaining nearly the same size and shape as the original lumps of coal. Cannel coal often takes a good polish, and can be worked into boxes and other articles.

Jet is an extreme variety of cannel coal in one direction, as *batt* or carbonaceous shale is in another.

Anthracite is heavier than common coal, with a glossy, often iridescent lustre, and a more completely mineralised appearance. It rarely soils the fingers, has a distinctly sharp-edged conchoidal fracture, or else breaks readily into small cubical lumps. It is not easily ignited, but when burning gives out an intense heat, so as to sometimes melt the bars of the grate or furnace in which it is used. It does not flame, and gives off but little smoke, being in this respect similar to coke or charcoal. In many ordinary coals little flakes of mineral charcoal occur, retaining that part of the vegetable structure called the vascular tissue. They are called "mother of coal" by the colliers in some places. It is frequently seen in the form of a thin silky coating, covering some of the surfaces of the coal. †

The Face or Cleet of Coal.—Most coals have a peculiar structure, which bears a slight analogy to the crystallisation of a mineral. They break or split not only along the bedding, but across it, along two sets of planes at right angles to the bedding and to each other. The smooth clean faces produced by one of these planes are more marked and regular than those produced by the other, as may be seen by examining any lump of coal. The principal of these division planes are called by the colliers the *face* of the coal, the other being called the *back* or *end* of the coal. They preserve their parallelism sometimes over very wide areas; and the mode of working or getting the coal, and the direction of the galleries, is governed by the direction of the *face*. It is a structure which is probably the result of the mineralising process undergone in passing from an organic to an inorganic state, or rather, perhaps, from an incoherent to a consolidated condition, and is a case of the "joint" structure of rocks, under which head it will be spoken of in a subsequent chapter. ‡

* Ronalds and Richardson, *Chem. Tech.*

† Microscopal examination exhibits not only the vascular but the cellular tissue of plants in the substance of many coals, as was shown by Mr. Witham in his work on the structure of fossil plants, and by many observers since. See also Harkness, *Edin. New Phil. Journal*, July 1854.

‡ See Chap. VII.

Composition of Coals.—The following analyses show the chemical constituents in some of the principal varieties of coal:—

	Lignite.	Splint Coal.	Cannel Coal.	Anthracite.
Carbon	71·0	79·58	66·4	91·44
Hydrogen	4·7	5·50	7·54	3·46
Oxygen	22·3	8·33	10·84	2·58
Nitrogen		1·13	1·36	0·21
Earthy substances	2·1	5·46	13·82	2·31

Under the head of shale, in a previous page of this chapter, reference was made to certain highly-bituminous strata which are now much employed in the manufacture of paraffin oil, and to which the name of **Oil-shale** has been given in commerce. These strata are in a geological sense true shales. They consist of fissile argillaceous layers, highly impregnated with bituminous matter, and while their extreme limit on the one hand passes into common shale, on the other it graduates into cannel or parrot coal. Of these oil-shales the richer varieties yield from 30 to 40 gallons of crude oil to the ton of shale. They are distinguished from non-bituminous or feebly bituminous shales by a peculiarity which is very marked throughout the shale districts of Scotland—viz. that when a thin paring is cut along a surface of shale it curls up in front of the knife, and leaves a brown lustrous streak. Some of the shales in that district are crowded with the valves of entomostracan crustaceans, and it is possible that the bituminous matter may in some cases have resulted from animal organisms, though the abundance of plant remains in the adjoining strata indicates that it is probably in most cases of vegetable origin.*

III.—AERIAL ROCKS.

The deposits accumulated by atmospheric agencies, such as drift-sand, soil, and brick-earth, do not form important rock-masses such as we have hitherto been considering. But the study of their formation is of the highest consequence in enabling us to understand the processes by which the surface features of the earth are modified. They will therefore be more fitly noticed under the section which treats of geological agencies.

IV.—METAMORPHIC ROCKS.

The rocks which are now to be described have received the name metamorphic, or altered, to indicate the fact that they are sedimentary (or in some cases igneous) rocks which are not now in their original condition, but have been subjected, at a greater or less depth within the crust of the earth, to a process called metamorphism, whereby a re-arrangement of their constituent elements has been effected, and in most cases a crystalline texture has been developed. The nature of this process will be more properly noticed in a subsequent chapter.

* Besides the entomostraca referred to in the text, scales of several species of small ganoid fishes (*Palæoniscus*, *Amblypterus*, etc.), are often abundant in the shales, while coprolites of some of the larger ganoids (*Megalichthys and Rhizodus*) are not uncommon.

At present we are concerned with the character and composition of the rocks themselves.

The metamorphic rocks may be divided into two sub-groups, those in which the original mineral texture is still recognisable—the particles, however they may have altered their form and state, not having entered into new combinations—and those where such new combinations have been produced. The former sub-group will accordingly consist of altered arenaceous, argillaceous, and calcareous rocks, while the members of the latter may be arranged in three sections—the compact or crypto-crystalline, the schistose, and the crystalline-granular or granitic.

SUB-GROUP I.

a. Metamorphosed Arenaceous Rocks.

Quartz-Rock or **Quartzite** is a compact, fine-grained, but distinctly granular rock, very hard, frequently brittle, and often so divided by joints as to split in all directions into small angular but more or less cuboidal fragments. Its colours are generally some shade of yellow or white, passing occasionally into red, and at other times into green. When examined with a lens it may be seen to be made of rounded grains, which appear to be imbedded in a purely siliceous glassy-looking cement. This cementation or semi-fusion of the grains shows at once that it is a sandstone which has been altered and indurated by the action either of heat alone or of heated water. Quartz-rock forms ranges of lofty mountains, as among the Highlands and Western Islands of Scotland, where it occurs as one of the members of a large metamorphic series. Along the sides of many trap-dykes, sandstone traversed by the dykes is found to be indurated into quartz-rock, and sometimes even made columnar, the columns ranging outwards from the surface of the dyke.

The student must carefully distinguish between quartz-rock or quartzite, as here described, and pure *vein-quartz*, which occurs sometimes as a white compact rock, in considerable mass, but always as a vein traversing other rocks. It has none of the granular structure characteristic of quartz-rock. The "quartz-rock," so often spoken of in Australia, is rarely, if ever, true quartz-rock, but vein-quartz; not an altered bed of sandstone contemporaneous with the rocks in which it lies, but a deposition in a vein or fissure produced subsequently to the consolidation of the rocks it traverses. In a collection of European rocks purchased from Krantz of Bonn by the Museum of Irish Industry, among seven specimens of so-called quartzite, at least five were undoubtedly *vein-quartz*, and not *quartzite*.

Greywacke.—A name given to certain forms of altered sandstone. Greywacke is a compact aggregate of rounded or angular grains of quartz, felspar, slate, or mica, cemented by a siliceous, argillaceous, or felspathic base. It is usually of some shade of grey, but may be brown, red, or blue. The distinguishing feature of greywacke, as compared with sandstone, is in the compact base and the way in which the grains seem often to pass into the base. In some varieties, indeed, it is often difficult to distinguish any rounded grains, and then the rock assumes the aspect of a microcrystalline igneous rock. This is especially the case where the greywacke is very felspathic, as it is in Ayrshire and other parts of Scotland.*

* See below, under the term "Metamorphic Porphyry."

β. Metamorphosed Argillaceous Rocks.

Flinty-slate (Lydian-stone).—Clay or shale has been in some cases, as in that of the Lias of Portrush, converted by contact with a large mass of igneous rock into a smooth, hard, brittle, splintery black rock. The fossils in the flinty-slate of Portrush are still perfectly preserved, though the rock is so hard as to have been originally described as basalt, and adduced by the Wernerians as a proof of the aqueous deposition of basalt. Many of the more siliceous shales of the lower Silurian Series of the South of Scotland have been converted into a similar substance. Lydian-stone was used as a test for the precious metals, their relative purity being shown by the nature of their streak upon the stone. Other altered clay-rocks are known as *Porcellanite* or *Porcelain-Jasper*, having a texture like porcelain.

Clay-Slate is a fine-grained fissile rock, differing from shale in being always highly indurated, and splitting into plates that are independent of the original bedding of the rock, sometimes coinciding with it, but frequently crossing it at all angles. This fissile structure or "cleavage" is a superinduced metamorphic one. The original bedding or lamination of the rock may frequently be traced, even in hand specimens, by means of parallel lines or bands of different colour and texture traversing the slate. These bands are called by Professor Sedgwick the "stripe" of the slate. Clay-slate is generally of a dull blue, grey, green, or black colour, sometimes "striped," sometimes irregularly mottled. The "cleavage" of slates will be treated of in the next part of this work as a petrological structure.

γ. Metamorphosed Calcareous Rocks.

Altered Limestone.—This was formerly called *Primitive*, and is even at the present day often called *Primary Limestone.* Since, however, it is known that many crystalline limestones are not Primary, that the statuary marbles of Italy and Greece, for instance, are some of them Secondary, and some even Tertiary limestones in a metamorphosed state, it would seem better to disuse the term *primary* as a mere lithological designation. Some limestones were originally formed as crystalline limestones, just as many parts of a coral reef and some stalactites are crystalline internally. Others, however, have certainly been only made to assume the crystalline structure at a period subsequent to their formation. In the well-known experiments of Sir James Hall, it was shown that even chalk could be converted into a hard crystalline marble, by being heated under such a pressure as should prevent the escape of the carbonic acid gas.

The chalk of the north of Ireland is all harder than that of England, and can never be used for making a mark on wood or stone. Where penetrated by trap-dykes it is altered into a hard, grey, semi-crystalline limestone in some places, in others into a coarsely crystalline white marble.

Saccharoid or *statuary marble* is a white fine-grained crystalline rock resembling loaf-sugar in colour and texture, working freely in any direction, not liable to splinter, slightly translucent, and capable of taking a perfect polish. Concealed flakes of mica or chlorite sometimes exist in it, as may be seen on examining the weathered surfaces of some of the ancient statuary in the British Museum and elsewhere.

In some saccharoid limestones, however, as in those which occur largely in Donegal, plates and layers of white silvery mica are much more abundant. Some of the beds of white saccharoid limestone split into plates not one-tenth of an inch in thickness, which are coated with micaceous flakes of a silvery lustre, forming very pretty specimens, but destroying the use of the rock for architectural and statuary purposes. Some of the beds, however, afford considerable blocks free from mica.

Other varieties of altered limestone are variously coloured, and more largely and coarsely crystalline. The white or coloured kinds, which will take a polish and can be used in the arts, are called marble.

Dolomite has already been described as one of the varieties of limestone. It is in many if not in most cases, however, the result of an alteration of common limestone, carbonate of magnesia replacing carbonate of lime. It is generally perfectly crystalline, either in large or small granules, and has often a porous texture, so that the crystalline granules can be seen to touch each other at only a few points. This causes them to be easily disintegrated, and fall into a kind of sand consisting of minute crystals of bitter-spar. It is often more largely cellular, having drusy cavities lined, and sometimes filled, with large crystals of bitter-spar. The colours are generally yellowish-white, yellow, or brown, sometimes reddish. In some dolomites fossil shells occur, which on examination show that the original carbonate of lime has been, particle by particle, removed, and replaced by carbonate of magnesia. The carbonate of magnesia seems to have been added to the rock from some external source, or, perhaps, in some cases, to have been originally diffused in small proportion through the whole mass of the limestone, and subsequently concentrated along certain lines, or into certain irregular spaces, so as there to form a perfect dolomite, and leave the rest of the rock a pure carbonate of lime. The bands of dolomite, often traversing limestone like vertical walls, are spoken of in Derbyshire and Yorkshire as *dunstone.**

There are some rocks called **Serpentine**, interstratified with highly metamorphosed rocks (like the serpentine marble of Ballynahinch, Galway), which are perhaps the extreme metamorphic form of a siliceous magnesian limestone, the carbonates being converted into silicates. Sir W. Logan, director of the Geological Survey of Canada, assured me that he had in that country traced serpentines which gradually passed into beds of unaltered magnesian limestone. Mr. Sterry Hunt describes the association of serpentines (or ophiolites) and ophicalcite.†

SUB-GROUP II.

In this division all trace of the original texture of the rocks is effaced, and in its place a new texture and mineralogical composition has been developed. The student will afterwards perceive, when we come to consider the process of Metamorphism, that as the metamorphic changes have been effected gradually and with varying intensity, so we meet with rocks in all stages of change. Hence it sometimes becomes difficult to determine to what rock-species some particular specimen or mass should be assigned, the transitional forms are so abundant, and their indefiniteness and variations so great. Add to this that in the present branch of our subject a vast deal of research still requires to be carried on before our knowledge of it can be considered at all commensurate with its importance. The following grouping is confessedly unsatisfactory, and is proposed merely provisionally until it is set aside by further research.

a. Compact or Crypto-crystalline.

Under this title is here included a series of rocks, many of which

* On the conversion of limestone into dolomite see Bischoff, vol. iii. chap. liii.

† *Report of the Geological Survey of Canada for* 1853 *and* 1856.

are still very imperfectly known. Some of them have manifestly resulted from the metamorphism of highly felspathic sandstones and argillaceous strata, and now appear with many of the characters of porphyritic and other truly igneous rocks.

Serpentine (*Ophite, Ophiolite*).—This rock has already been alluded to as intimately associated with altered limestones, and is itself probably in many cases a further stage in the metamorphism of magnesian limestone. But it may doubtless be sometimes the result of the metamorphism of augitic or hornblendic or olivine-bearing rocks. It is compact, dull, usually some shade of dirty green, with a splintery fracture, and easily scratched. It may be briefly described as a hydrated silicate of magnesia. It occurs sometimes in small veins and layers associated with limestone, sometimes in large masses which trend with the strike of the surrounding rocks, and form ranges of hills. The following analysis of Dr. Haughton shows the chemical composition of a red serpentine from Cornwall:— *

Silica	38·29
Protoxide of iron	13·50
Magnesia	34·24
Loss by ignition or water	12·09
	98·12

The specific gravity of serpentine is about 2·5.

Metamorphic Porphyries.—In the county of Ayr the lower Silurian rocks and the lower Old Red Sandstone show some remarkable examples of metamorphism. In the neighbourhood of Ballantrae the Silurian greywacke, which is often highly felspathic, is altered into various dull, compact, or finely-crystalline and porphyritic rocks. Conglomerate also is found passing into similar dull compact masses, which are sometimes full of vesicles like an amygdaloid. These rocks are associated with, and run more or less parallel to, masses of serpentine, diorite, and syenite. Their true chemical and lithological relations are still to be determined.†

β. Schistose.

The Schistose Rocks are those which have a *schistose* or *foliated* texture.

"Foliation" is a term applied by Professor Sedgwick ‡ to those rocks which have had such a subsequent texture and structure given to them as to split into plates of different mineral matter, either with the bedding or across it. Such rocks are called "schists." *Cleavage* indefinitely splits a rock, either with the beds or across them, without altering its mineral character, and thus produces "slate." *Lamination* will then be the remaining term applicable to "shale," and signifying the splitting of a rock into the original layers of deposition. When, therefore, we wish to be precise, we can speak of the *foliation* of *schist*, the *cleavage* of *slate*, and the *lamination* of *shale*.

Mica-schist consists of alternate layers of mica and quartz, the mica generally formed of a number of small flakes firmly compacted together, and the quartz more or less nearly resembling *vein*-quartz. Many mica-schists, however, contain

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* *Phil. Mag.* x. 253.

† They have been mapped by the Geological Survey, and are described by Mr. James Geikie, *Quart. Jour. Geol. Soc.*, vol. xxii. p. 513. See also *Catalogue of Rock Specimens in the Edinburgh Museum*, pp. 49 and 54-6.

‡ See his paper on the "Structure of Large Mineral Masses"—*Geological Transactions*, vol. iii. pp. 479 and 480. For further remarks on Foliation, see Chap. X.

comparatively little quartz, and seem scarcely to differ from clay-slate or shale, except in the shining surfaces of their plates or folia, which look as if all the particles of which they were originally composed had been blended together so as to be no longer separable. Mica-schist has often a minutely corrugated or crumpled structure, the layers being bent into sharp vandykes of one, two, or more inches in height and width. The separation into layers, or foliation of mica-schist, generally coincides with the original bedding of the mass, but sometimes may be independent of it. In the latter case, it may in some cases have taken the direction of a previously existing cleavage. The foliation would indeed tend to follow the dominant divisional planes of the rock, whether bedding or cleavage.*

In the Scottish Highlands some of the mica-schists pass into strata which hardly differ from fissile micaceous sandstones. On the other hand, many soft highly micaceous sandstones seem to require only a little induration and blending of their particles to form "mica-schist." In parts of the New Red Sandstone of central England, the rock is so highly micaceous as to split into thin flags of a quarter of an inch in thickness and a foot in diameter ; and these can be split by the nail into still finer flakes, all the surfaces glittering with micaceous lustre. In these cases it is obvious that the mica was deposited in layers of mica spangles already formed. But it is conceivable that a minor degree of metamorphism might suffice in such rocks to form mica, in addition to that already existing, and the two might, perhaps, coalesce into layers, leaving the quartz grains of the sandstone as intermediate layers of quartz. The student must be careful to distinguish between rocks originally micaceous in consequence of the deposition of spangles of mica together with the other materials, and those in which the micaceous sheen and the tendency to split into micaceous folia are the result of subsequent metamorphic action, producing mica where it did not before exist, or, at all events, was not apparent. It is to the latter only the term *mica-schist* should be applied.

Chlorite-Schist.—A schistose aggregate of chlorite, usually with a little quartz, and often with felspar, mica, or talc. *Potstone* is a more massive form of chlorite-schist, and receives its name from the fact that it can be turned in the lathe and worked into articles of domestic use.

Talc-Schist.—A schistose aggregate of scaly talc laminæ, usually with quartz or felspar.

Granulite (*Leptynite, Schistose Eurite*).—A schistose aggregate of felspar and quartz with scattered garnets. The felspar (probably both orthoclase and a plagioclase felspar) is the predominant ingredient, and in it the quartz occurs as flattened grains or very thin lamellæ.

Schorl-Rock (*Schorlaceous-Schist, Tourmaline-Rock*).[1]—An aggregate of grains of quartz and of schorl (tourmaline), sometimes schistose, sometimes granular, and sometimes compact. Several other allied rocks may be mentioned here, as *Greisen*, consisting of quartz and lithia-mica ; *Eclogite*, a granular aggregate of grass-green smaragdite and red garnet ; *Garnet-Rock*, garnet, hornblende, and magnetic iron.

Hornblende-Schist consists of dark-green or black hornblende, the particles being felted together, and lying in one prevalent direction, so as to give a schistose texture. When the mass loses its schistose character and becomes a crystalline aggregate of hornblende, it is known as *Hornblende Rock*.

Actinolite-Schist is a variety of hornblende-schist, the mineral actinolite taking the place of common hornblende. With regard to this and similar schists,

* See Ramsay, *Quart. Jour. Geol. Soc.* ix. 172. The coincidence of foliation with bedding over the Scottish Highlands is insisted on by Sir R. Murchison and Mr. Geikie, *op. cit.* vol. xvii.

it may be remarked that there is reason to believe that, as they occur among altered sedimentary rocks, they may represent former trap-rocks.

Gneiss.—This rock, when found in its typical condition, consists of the same mineral ingredients as granite, the distinction between the two rocks being in the manner in which the component minerals are arranged. In gneiss the quartz, felspar, and mica occur in irregular lenticular layers, and are, so to speak, felted into each other, forming in this way the well-known schistose texture of the rock. The word Gneiss, however, has often been very vaguely and indefinitely employed to signify any hard quartzose semi-crystalline schistose rock, to which no other name could be easily given.

Some gneiss can only be distinguished from granite by the regular arrangement of its component crystalline particles in a certain parallelism, so as to give it a slightly schistose structure, or "grain," as it is called by Professor Sedgwick. Other varieties of gneiss, again, can only be separated from mica-schist by the occasional occurrence of little plates of felspar in addition to the layers of mica and quartz. In hand specimens, indeed, it is often very difficult to draw any sharp line of separation between mica-schist and gneiss, the more fissile specimens being called mica-schist, while the firmer ones would be called gneiss. Even in the field they are often so blended together, and alternate with each other so frequently, that their separation is impossible. As mentioned under section *a* of this sub-group, large masses of schistose rock also occur sometimes in metamorphic areas of such an indeterminate character that it is difficult to give them any distinctive appellation.

Gneiss might, indeed, in its purest and most typical form, be termed schistose granite, consisting, like granite, of felspar, mica, and quartz, but having those minerals arranged with a certain degree of parallelism rather than in a confused aggregation of crystals. In speaking of it as schistose granite, however, we must never forget that true gneiss was never really a granite or igneous rock which, on cooling, assumed a peculiar laminated structure,* but that it was originally a laminated mechanically-formed rock, a *sandstone* more or less argillaceous, containing, indeed, the elements of quartz, felspar, and mica, but not exhibiting any more appearance of those minerals at its first deposition than is exhibited by any of the ordinary unaltered sandstones with which we are familiar. There are cases, however, where true granite, as in parts of the granite of the south-east of Ireland, passes into a rock that might be called gneiss from the parallel arrangement of its mica flakes.†

Some of the metamorphic rocks of the Alps, on the other hand, which are probably in reality gneiss, nevertheless resemble granite so completely, that no one looking at a hand specimen, or even a single block, however large, would venture to pronounce it other than a genuine granitic rock, formed of a confusedly crystalline aggregate of felspar, quartz, and a dark green mineral which is like a dull earthy mica. I believe some of this granitic-looking rock, if not all of it, to be the so-called Protogine. If it were true intrusive granite, it would, as Professor Haughton has remarked, be difficult to believe the third mineral to be talc, *i.e.* a pure silicate of magnesia. But, whatever be the exact nature of the third mineral, I do not believe the rock to be intrusive granite, but a granitoid gneiss.‡ Lithologically,

* The student, however, should consult the suggestive remarks of Mr. Scrope on the analogy between the foliation of gneiss and the schistose structure of some volcanic rocks. See his work on *Volcanoes*, p. 139 and chap. xii.

† Some of the masses in Newfoundland to which Mr. Jukes gave, when surveying them in the year 1839, the name of Granite without any hesitation, are now termed Laurentian Gneiss by the officers of the Canadian Geological Survey under Sir W. Logan.

‡ I am alluding now to the rock as seen in the Hasli valley about the Handek waterfall, and about the Grimsel Hospice.

it is doubtless not to be distinguished from granite, but its petrological relations prove it to be a metamorphic rock, in consequence of its bedded character and its regular interstratification with every variety of mica-schist and gneiss, and that often in beds not more than a few feet in thickness. There seems to be a regular alternation between the most granitic and the most earthy schistose bed, the extreme varieties sometimes lying in direct apposition against each other, sometimes separated by intermediate gradations. The granitic beds, too, are certainly not intruded veins, but run evenly between the other rocks, and were evidently contemporaneous with them. In Donegal and Connemara again large tracts of porphyritic granite, in which no trace of foliation is perceptible for many miles, are found to exhibit a parallel arrangement of their mica-plates as we approach their boundaries, and within the space of half-a-mile or so to lose their porphyritic character, become finer grained, and gradually assume a foliated structure, and eventually pass into regular stratified beds of various characters, but with no resemblance to granite. Farther observations on these rocks will be made when we are examining the subjects of cleavage and foliation.

Conglomeratic Mica-Schist or Gneiss.—In the pass of the Tête Noire, between Martigny and Chamounix, the traveller may see, just opposite the door of the Tête Noire Hotel, even a conglomerate converted into a metamorphic rock. This is a confused aggregate of mica-flakes, enclosing and surrounding pebbles of white quartz, which vary in size from that of a nut to that of a man's head. The mica was not deposited in worn spangles as a mere micaceous sandstone or clay enclosing quartz pebbles; or if it was so formed, those worn micaceous spangles have been made to blend together again, and form a rough mica-schist, enveloping the pebbles in continuous flakes like any other mica-schist.

Beds of conglomerate also occur among the mica-schists of the N.W. of Ireland, the pebbles being enveloped in mica-schist, and sometimes having a micaceous glaze on their surfaces, so as to prove the "micacisation" of the rock to have been imparted to it subsequently to its formation. The same fact has been noticed by Mr. Geikie among the clay-slates of the island of Bute.

γ. Crystalline-granular or Granitic.

In this series of metamorphic rocks are included those in which, while all trace of the original texture has disappeared, the component elements have re-arranged themselves into new mineralogical combinations, and have assumed a crystalline texture quite undistinguishable from that of rocks ordinarily called igneous. Between rocks of this class and the more crystalline varieties of the schists there is the closest relationship. It has already been remarked that gneiss and granite are found sometimes to pass into each other, and that there is no mineralogical difference between the two rocks; their distinction being merely in the amorphous crystalline aggregation of the one, and in the schistose texture of the other. It was likewise mentioned that gneiss is found alternating with and passing into mica-schist, while mica-schist in turn shades off into the less highly metamorphosed varieties of metamorphic rocks, and those again into sedimentary strata that have not been metamorphosed. Hence we can trace a gradual series of stages in the alteration of rocks, until we pass finally true crystalline granite. When, moreover, we proceed to study the rocks in the field, we find that, at least in many cases, the granite is not found disrupting the stratified rocks,

but occupying their place, and that, after tracing them up to the granite on the one side, we find them re-appearing on the other with the same dip and strike. From these and further observations, to be described in a subsequent chapter, it has been inferred that granite must be, at least in many cases, a truly metamorphic rock—the ultimate result of the metamorphism of which mica-schist and gneiss are preliminary stages. Between granite which has broken through surrounding stratified masses, and is called an igneous rock, and metamorphic granite, no well-marked lithological distinction has yet been determined.

But, besides granite, there are other crystalline rocks associated in such a way with metamorphic rocks that their metamorphic origin is by many geologists more than suspected. Some of these rocks have already been given in the section devoted to igneous rocks. But their names are repeated in this place, to remind the student that they sometimes occur in such an intimate relationship with undoubtedly metamorphic rocks as to suggest a common origin for the whole.

Granite.—What has been regarded as metamorphic granite occurs in different parts of the British Islands. The granites of Galway and Donegal are with difficulty separable from the surrounding gneiss, and the whole appears to be of metamorphic origin. In the south of Scotland the Silurian and Old Red Sandstone rocks here and there pass into a form of gneiss which is succeeded by granite.*

Syenite of metamorphic origin occurs in Ayrshire, where it is associated with diorite and serpentine, among very much altered Silurian rocks. Large masses of syenite occur among the metamorphosed lias limestones of Skye. Mr. Geikie has suggested, however, that these syenites, and possibly some in Mull, may be connected with the great tertiary volcanic series of the Western Islands.†

Diorite, Diallage-rock.—Masses of these rocks occur in the metamorphic region of the south of Ayrshire.

Hypersthene-rock.—This rock occurs among the Laurentian gneiss of Canada. A large mass of it exists in the island of Skye, which it has been suggested is of metamorphic origin.

Miascite.—A large-grained granitoid aggregate of orthoclase, elæolite, and black mica. It is closely related to the rock named zircon-syenite.

Geological age of Metamorphic Rocks.—In Western Europe, metamorphic rocks, such as Clay-slate, Quartz-rock, Mica-schist, and Gneiss, are usually found only among the older geological formations. Hence naturally arose the notion among the earlier geologists that such rocks were only produced in the earlier geological periods. It is, however, now well known that some of the Clay-slate used for roofing slate in the Alps was formed during the same great geological period as the clay on which London stands, and it is believed that the mica-schist and gneiss of some districts are at least as modern as the chalk of Britain. The student therefore must guard himself from taking it for granted that any of the lithological textures or characters of such rocks can be taken

* See the remarks already made under the term *Protogine*, *ante*, p. 124.
† *Proc. Roy. Soc. Edin.*, vol. for 1866-67.

as certain indications of their geological age independently of other evidence.*

In completing this summary of the leading characters of the more important rock-masses which constitute the crust of the earth, we would again direct the attention of the student to the works enumerated at the head of this chapter, where much more detailed information will be found than can be given in such a Manual as the present volume is intended to be. It may be useful to present here a table of the rocks already enumerated,† that the reader may see at a glance the classification here adopted, and the place in it which is assigned to each of the rocks.

A TABULAR CLASSIFICATION OF ROCKS.

I. IGNEOUS ROCKS.

A. Volcanic.

Felspathic.	Trachydolerites, or intermediate varieties unnamed.	*Augitic.*
Trachyte.		Dolerite.
Pearlstone.		Anamesite.
Andesite.		Basalt.
Clinkstone or Phonolite.		Wacke.
Obsidian.		
Pumice.		
Trachyte-tuffs and breccias.		Peperino, doleritic tuffs, breccias, and slags.

B. Trappean.

Felspathic.	Intermediate varieties unnamed.	*Hornblendic and Pyroxenic Felspar and Hornblende, etc.*
Felstone.		Diorite.
Pitchstone.		Diallage-rock.
Clinkstone.		Hypersthene-rock.
Minette.		Melaphyre.
Kersanton.		Diabase.
Kersantite.		Aphanite.
Porphyrite.		Wacke.
Felstone tuff and Porphyrite tuff, with breccias and conglomerates.		Greenstone tuff, with agglomerate, breccia, and conglomerate.

* For further information regarding metamorphism and metamorphic rocks the student is referred to the chapter in which metamorphism as a geological process is specially dealt with.

† And also some which are now in course of formation, and which fall to be described under the section of Geological Agencies.

C. Granitic.

Granite. Syenitic granite. Pegmatite. Protogine. Graphic granite.	Syenite and its varieties.

II. AQUEOUS ROCKS.

Mechanically Formed.

Arenaceous . . .	Gravel or Rubble, which, when compacted, forms Conglomerate or Puddingstone, and Breccia. Sand, which, when compacted, forms Sandstone, Gritstone, and their varieties.
Argillaceous . . .	Clay and Mud, Loam, Marl. Shale or Slaty-clay, Mudstone.

Chemically Formed.

Calcareous . . .	Stalactite and Stalagmite, Travertine, etc. Some Limestones and Dolomites.
Siliceous . . .	Siliceous Sinter.
Gypseous . . .	Gypsum.
Saline . . .	Rock Salt.

Organically Derived.

Calcareous, mostly from animals	Limestone and its varieties, compact, crystalline, chalky, oolitic, pisolitic, some magnesian, etc.
Siliceous, probably from animals	Flint and Chert.
Carbonaceous, mostly from plants .	Peat, Lignite, Coal, Anthracite, Graphite.

III. AERIAL OR EOLIAN ROCKS.

Blown Sand on coasts ; Sand-hills of deserts ; Calcareous Sands compacted by rain, etc. ; Debris at foot of cliffs ; Soil.

IV. METAMORPHIC ROCKS.

Sub-Group I.—Those in which the Original Mineral Texture is still recognisable.

a. Arenaceous.

Quartz-rock or Quartzite.
Greywacke.

β. Argillaceous.

Flinty-slate.
Clay-slate.

γ. Calcareous.

Altered Limestone. Marble.
Dolomite.

Sub-Group II.—Those in which the Original Mineral Texture has been effaced.

α. Compact or Crypto-crystalline.

Serpentine.
Metamorphic Porphyries.

β. Schistose.

Mica-schist.
Chlorite-schist, Potstone, Talc-schist.
Granulite.
Schorl-rock.
Hornblende-schist, Actinolite-schist.
Gneiss.

γ. Crystalline-granular or Granitic.

Granite.
Syenite.
Diorite.
Diallage-rock.
Hypersthene-rock.
Miascite, and probably other rocks enumerated among the Igneous series.

Section II.

PETROLOGY.

CHAPTER VI.

FORMATION OF ROCK-BEDS.

The term Petrology * is here used quite arbitrarily to signify the study of rock masses; that is to say, the examination of those characters, structures, and accidents of rocks, which can only be studied on the large scale, and only be observed in "the field." It will include the modes of stratification, of separation by divisional planes, of fracture and disturbance, the methods of occurrence, and form of igneous, aqueous, and metamorphic rocks, and the formation of mineral veins.

Lamination and Stratification.—The lamination and stratification of the aqueous rocks is the very foundation of geology, that on which all the more important deductions of the science are based. It is therefore necessary to describe these structures in some detail.

Rocks that have been formed by the strewing of materials in water, and the deposition of those materials in beds or *strata*, are called stratified rocks, and this structure is called their stratification. As each bed, or *stratum*, was formed by the deposition of successive layers, or *laminæ*, that structure may be called their *lamination*, and it will be found convenient to restrict the term to such layers of deposition, and not to extend it to any other layers or plates that may have been subsequently produced in the rocks.

Strata vary in thickness from less than an inch to many feet.

Laminæ rarely exceed an inch in thickness, and vary from that down to the thinness of the finest paper.

Planes of Lamination.—The very fine laminæ (plates or layers) of which some beds of shale are made up, are obviously the result of separate acts of deposition of fine sediment, film after film, upon the bottom of some tranquil or very slowly moving water. We may suppose this sediment to have been carried into the water by successive tides bringing matter from some neighbouring shore, by periodical floods of some river, or by the gradual action of some current. Whatever may have been the exact nature of the action, it was clearly a gradual one.

* See *ante*, p. 6.

Some considerable time must be allowed for the deposition of a bed even *one* foot thick, when we find it made up of distinct laminæ, fifty or a hundred of which may be counted in each inch of its thickness. This time is that required for the mere act of settlement of the materials in the water, without calculating that which is requisite for their transport from some distant locality. Still, although some time was required, and although the acts of deposition were distinct, yet they were not so widely separated in time as to allow of any great consolidation of one layer before the next was deposited upon it. The whole set of laminæ succeeded each other so as to cohere together, and form *one* bed, which may be quarried and lifted in *single* blocks. In some shales, certainly, the coherence between the laminæ is but slight ; they may be pulled asunder by the hand ; but in others it is more complete, and in some quite firm ; and in some fine-grained laminated grits and sandstones, it requires almost as much force to split them along the lines of lamination (*with the grain*, to use a common term) as it does to break them across. In such instances, it is probable that the succession in the acts of deposition was a more rapid one, than when the laminæ separate more easily. The mere degree of coherence, however, of the laminæ of a stratum is by no means so sure a test of the shortness of the intervals between their deposition as their distinctness is of its length, since all the subsequent actions of pressure and cementation tend to make them cohere, while no action tends to separate them, unless that of weathering close to the surface.

Planes of Stratification.—The planes of stratification differ from those of lamination, chiefly in being on a larger scale, partly also in as much as they usually mark a want of coalescence between two successive layers of rock. It is not usual to get a block consisting of parts of two beds, since the parts will fall asunder and make two blocks. It is true that in some cases parts of two beds may partially adhere together if carefully removed, but this is obviously the adhesion of two things, and not their coalescence into one. It is also true, that in some rocks the lamination, and in some even the stratification, is more or less obscure. In such cases, the indistinctness may be due either to the comparative rapidity and continuousness of the act of deposition, or to the subsequent obliteration of structures once possessed.

If the coherence of the laminæ of any kind of rock is owing to the comparative shortness of the intervals between their deposition, it follows that the want of coherence between one bed and another of the same kind of rock is the result of the length of the interval between the deposition of the beds. Each bed had time to become so much consolidated before the next was deposited upon it, that the latter could not coalesce with the former. A plane of stratification, then, marks a pause in the act of deposition ; the duration of that pause being very

considerably longer than that of the intervals between the successive laminæ.

In using the term "plane," we, of course, must not take it in its strict mathematical sense, since the surfaces both of laminæ and beds are often uneven. In speaking of the planes of lamination, moreover, we must often understand merely the direction in which the laminæ are arranged, whether they be separable from each other or not. When we examine a cliff or a face of rock which cuts across the planes of lamination or stratification, we see merely the edges of these so-called planes, and speak of them as *lines*.

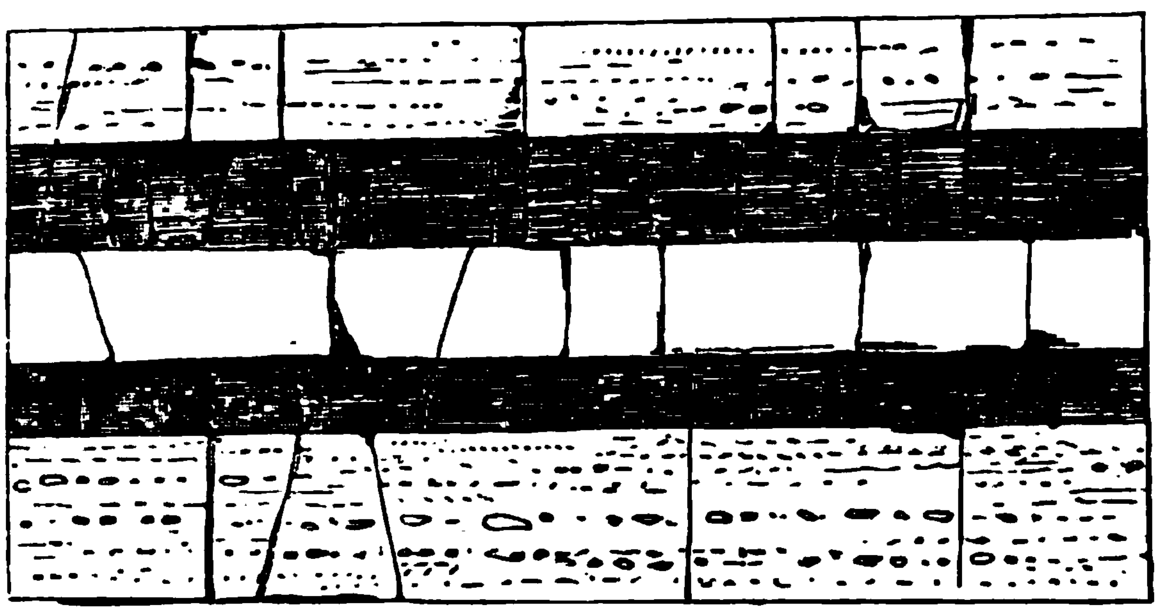

Fig. 23.

The above fignre, No. 23, gives a rude representation of the above facts, the dark-lined beds being meant for finely-laminated shales, the dotted beds for sandstones, and the one unmarked for a limestone, in which the lines of lamination are supposed not to be discernible. The student, however, is earnestly requested to study them for himself in any and every quarry of stratified materials that may be accessible to him, and warned that, without such direct observation of facts, and independent reasoning on them, his knowledge must always be incomplete, if, indeed, it can be called knowledge at all.

Length of Interval between Beds.—If we are at a loss to estimate the length of the interval between the deposition of the successive laminæ of a bed, still less have we the means of calculating the time which elapsed between the formation of one bed and that which rests upon it. When two or more successive beds are of precisely similar character, we should naturally suppose that the interval between bed and bed was not indefinitely greater than that between lamina and lamina. If we gave months to the one, years might be given to the other; if years to the one, centuries might be allowed to the other. Still we should have no certain grounds to go on, and the interval between bed and bed might be thousands of years for anything we could,

in the majority of instances, show to the contrary. When, moreover, the two beds were of totally different characters, we should usually feel called upon to allow a larger interval between their deposition than where the beds were similar. Some time must be required for a change to take place in the conditions of the neighbourhood. In the case of a bed of sandstone destitute of all argillaceous matter, resting on a bed of shale, we should be obliged to suppose some alteration in the strength or direction of the currents, so that all the finer matter was swept away, and only the coarser or heavier deposited. In the case of a shale resting on a sandstone, we should suppose that the current had diminished in velocity. In either case the current might have come from a new quarter, where only the particular kind of material was to be got.

The same current of water, charged with a mixture of gravel, sand, and mud, and having strength enough to carry it all on together, will, as its strength lessens, sort and separate the materials from each other, depositing them in the order of their coarseness, the pebbles and coarse sand first, next the finer sand, and lastly the mud.* Three different kinds of rock, then, might be deposited at the same time by the same current in different places. But in order that either sand or gravel may be thrown down at a subsequent period on the top of the mud, a fresh current either of greater velocity or from a nearer source will be required, while an interval will be necessary for the mud to consolidate so far as not to be removed by the new current, and not to allow the fresh pebbles or sand to sink into it.

In the case of a limestone occurring either on shale or sandstone, we are still more forcibly led to the supposition of a great change of conditions. If the limestone be a pure carbonate of lime without much or any admixture of mechanical detritus, it is obvious either that all currents had ceased in the water, or else that they were no longer able to get any earthy matter and transport it to that place. If, indeed, as seems necessary in the case of all marine limestones, we assign an organic origin to this rock, we are compelled to allow a period prior to its production sufficient for the animals from which it was derived to grow and to secrete their solid materials from the adjacent water.

It is possible, indeed, in some cases, by the aid of the remains of animals and plants found fossil in the rocks, to arrive at something like a rough approximation to the time which has elapsed between the formation of successive beds, so far as to say whether it was long or short. There are cases, for instance, in which we find on the surface of a bed of limestone the roots or attachments of a particular class of marine animals, called encrinites, which, when alive, were fixed to the rock by a solid

* Just as is shown for mud of different degrees of coarseness in Mr. Babbage's observations, to which reference will be made when we come to treat of the operation of geological agencies.

calcareous base. These attachments are those of animals of all ages, and are in great numbers; and in a bed of clay which rests immediately on the limestone, there are found a multitude of the remains of the upper portions of these animals, likewise of all sizes and ages (see Fig. 24). Now it is plain that in this case, after the limestone was formed, there was an interval during which the sea remained free from sediment, and

Fig. 24.*

Beds of oolitic limestone covered by brown clay containing fragments of encrinites. Living encrinites attached to sea-bottom.

therefore well adapted for the growth of these creatures. We do not know how long it remained so before any of them began to live there, but after a time they settled on the limestone at the bottom of the sea, and flourished there for a sufficient period to allow of successive generations arriving at maturity undisturbed, before the time when a quantity of mud, having been carried into the water, was deposited upon them, killed them, and buried their remains. Some of these remains, even the insides of the joints, are coated over with the calcareous cases of serpulæ (a kind of sea-worm), showing that they had been unburied in the bottom of the sea for some years, while their descendants were growing about them. Here, then, we have an interval of many years, if not of centuries, between the formation of two beds which rest directly one upon the other. Many instances similar to this occur to the geologist when pursuing his investigations, although not often admitting of such clear illustration and description.

There may be seen in the great limestone, called carboniferous limestone, in Ireland, a bed of corals in the position of growth which must have required a long series of years. These corals, of a kind called Lithostrotion, grow in bunches sometimes nine feet across, resting in the position in which they flourished on their old sea-bed, and proving probably many years of undisturbed tranquillity to have elapsed between the time of the formation of the bed on which they grew and the bed which finally covered them.†

* Copied from Lyell's *Manual.*

† See the figure and description of Mr. A. B. Wynne, in the explanation of sheet 145 of the Geological Survey of Ireland.

On the other hand, we have instances of fossil trees passing through several beds of sandstone, in such a way as to show that the whole number of beds were accumulated after the tree had sunk, and before it had time to rot entirely away. But a tree thus wholly buried in water will last many years before it is entirely decomposed, so that it might very well have become enclosed in several beds of sandstone, especially when we recollect that it forms an obstacle to the currents flowing by it, and thus tends to check their force, and cause the deposition of sand around it more rapidly than would otherwise take place. A case is mentioned of the stumps of pines still standing erect on the bottom of the sounds along the coast of North Carolina, although the submergence of the land on which they grew must have taken place before the settlement of the colony.* Still, whatever number of years we assign to the accumulation of the whole mass of sandstone, we should be inclined in this case to suppose the deposition of the sand to have been comparatively rapid, and the intervals between the deposition of the beds comparatively short.

It is possible in some cases, even without the aid of organic remains, to discover that the interval between two adjacent beds was a long one. For instance, we not unfrequently find that two beds, which in one place are contiguous, do in another place let in one, two, or more separate beds between them, as in Fig. 25, which is taken from a sketch made in a quarry at Donnybrook, near Dublin, by Mr. Du Noyer. It is obvious, that if we observed the beds *a e* at the spot marked A, we should only suppose an ordinary interval to have elapsed between the times of their deposition; while, on tracing the beds to B, we are compelled to enlarge that space of time sufficiently to allow for the formation of the beds *b*, *c*, and *d*, and the *intervals between them.* It appears, then, that while we are able to assign a sort of rough limit to the time required for the deposition of one bed, composed of a number of laminæ, we can rarely assign any approximate limit to the time required for the formation of a number of beds. Not only have we to multiply the first period by the number of the beds, but to allow for an equal number of intercalated intervals, of altogether uncertain duration, to represent the pauses that occurred between the formation of each two contiguous beds.

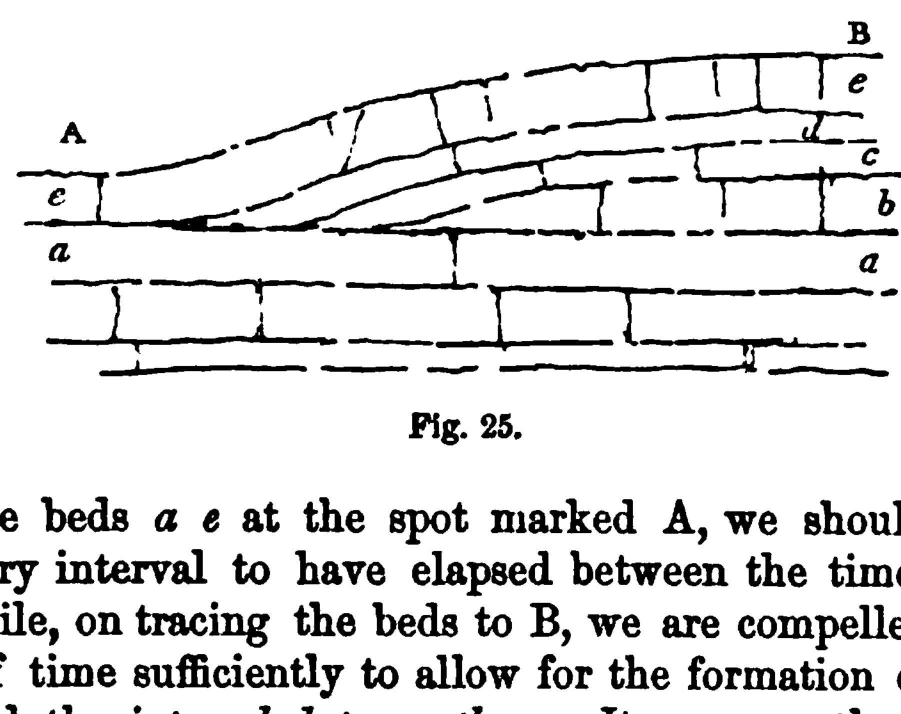

Fig. 25.

* Emmon's *American Geology.*

These intercalated intervals would be most probably *greater* than the periods of deposition, because we cannot imagine any circumstances that can keep up a continuous or rapid deposition of earthy matter, whether chemical or mechanical, for a long period of time, in any one particular locality. All we know, or can conceive, of the accumulation of earthy matters in the seas or lakes of the present day, shows the action to be partial and occasional, a bed of sand being formed here, a patch of mud deposited there, a bank of pebbles accumulated in one place, a bed of oysters or other shells growing in another, so that the bottom of the sea becomes gradually covered by several unconnected patches of deposition of different kinds, lying side by side. All our experience shows that for any great thickness or vertical succession of beds like these to be formed, in other words, for the depth of water to be materially diminished (except in narrow bays and inlets), a great length of time is required. The soundings in shallow and well-frequented seas, such as those around the British Islands, certainly do not alter very rapidly, although they doubtless do change in the course of centuries. In sea-charts the character of the bottom is marked in different places as "mud," "sand," "sand and shells," "small stones," and so on, and these characters remain sufficiently constant to be used for many years, in combination with the depth of water, as a guide to the seaman, and enable him to determine the situation of his vessel.

In a vertical series of beds of rock, then, we may feel sure that each bed will be to that below it like Salius to Nisus in the foot-race, "proximus huic, longo sed proximus intervallo;" and a third will follow "spatio post deinde relicto." Whether we take the whole earth generally, or any particular sea or ocean, and limit ourselves to the consideration of any given period of time, we must look upon the deposition of mineral matter as the exception, not the rule. Of many hundred thousand square miles of sea, only one perhaps is receiving at any one time the accession of any mineral matter on to its bed. The next successive deposition may be very long deferred, and may occur either in an adjacent or in a widely separated locality; and a vast number of these partial and detached acts of formation will be required before the whole of any particular area can be covered with one or more beds of rock. In reasoning on the methods of production that have been concerned in the formation of our great series of stratified rocks, which are nothing else than so many old "sea-bottoms," we are compelled to suppose a gradual, partial, and interrupted action to have operated in their accumulation, like that which is producing similar beds in the seas and lakes of our own time.*

Let any one visit any quarry, and place his finger on the edge of the plane of stratification between two successive beds, and it will be impossible for him to say how far the interval marked by that plane of separation equals or exceeds the intervals required for the deposition of the two beds. It may often indicate the lapse of thousands of years, for anything that we can say to the contrary.

Length of Interval between Groups of Beds.—When we rise from the consideration of a series of single beds to that of a succession of groups of beds, we find instances, on a still larger scale, of intervals having taken place in the deposition of strata, which at first sight appear perfectly continuous. Mr. Prestwich† shows that on examining the rocks called Tertiary, which lie above the Chalk in France, they appear to have a

* It is unavoidable that here and elsewhere in this section of the Manual we must to some extent anticipate information to be given in more detail and with fuller reference to the existing operations in a subsequent series of chapters, or presuppose a certain amount of acquaintance with these operations on the part of the student.

† In his paper on the "Correlation of the Eocene Tertiaries of England, France, and Belgium," *Journ. Geol. Soc.*, vol. xi. p. 211.

regular continuous sequence of beds of sand, and clay, and limestone, in which there is no sign of any interval having happened, while in reality a group of the English tertiaries, known as the London clay, having a thickness of nearly 500 feet near London, was deposited in an interval between the formation of two of the French sets of beds.

Mr. Prestwich says, speaking of the series as it exists in France, "Lithological structure and superposition seem to indicate a complete and perfect series. . . . It would nevertheless seem that there is a very important interval between the 'Lignites of the Soissonnais' and the 'Lits Coquilliers,' and that at so short a distance as from Kent to the Department of the Oise, there is introduced, wedgeshaped, between these two deposits, the large mass of the London clay, with its multitude of original organic remains. Yet there is not only no evidence either of the great lapse of time, or of the important physical changes which such a formation indicates, but there is even no cause for suspicion of such a fact in the apparently complete and continuous series of the 'Sables Inferieurs' of the north of France." We cannot conceive the London clay to have required less than some thousands of years for its formation, and it may more probably have been many tens of thousands, during which interval either no corresponding deposition was taking place over the area now forming part of the north of France (though deposition did take place both before and after this period, equally in the seas which covered what is now France, and what is now England), or if any corresponding strata were laid down, they have since been removed in such a way as to leave no trace of their ever having existed, or of the process of "denudation" by which they were removed.

These facts have not hitherto been sufficiently insisted upon, since they have a most important bearing on the theoretical conclusions of geologists. We have been too apt to regard solely the positive evidence of lapse of time, afforded by a successive series of beds, and to suppose that succession to have been continuous when it was in fact a most broken and interrupted one.*

Extent and Termination of Beds.—The fact that a set of beds is present in one locality and absent in another, whether that set be one of the large groups which we call "formations," or merely two or three beds ending in a quarry, as in Fig. 25, leads us to another conclusion respecting beds of stratified rock, namely, that although sometimes very widely spread, they were not of indefinite extent, but did end somewhere. This ending is generally a gradual one, the bed or set of beds becoming thinner and thinner, till at last it disappears. Sometimes, however, the termination is more abrupt.

The extent of single beds is most certainly ascertained in coal-mining, in which the horizontal (or lateral) extension of beds is followed. For instance, in South Staffordshire a bed of smooth black shale, a little below the Thick or Ten-yard coal, is known as the "Table batt." It has a thickness of from two to four feet, and extends over all the greater portion of the South Staffordshire coalfield—

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* As the result of my thirty years' experience of observation and reflection on stratified rocks, I am inclined to regard their formation as a series of partial and exceptional acts, instead of a normal and continuous operation; while even of the series that was formed, we have in many cases only the ruins remaining.

places where it is known being ten or twelve miles apart from each other in different directions. Its original extension was probably much greater, since the beds now disappear in one direction by "cropping out," and are buried in others at too great a depth to be followed. Known beds of coal, with a particular designation, such as "Heathen coal," extend over still wider areas, and similar facts occur abundantly in most coalfields. Mr. Hull says, "that one bed of coal called in part of the Lancashire coalfield the 'Arley mine,' but known by other names in other parts, spreads over the greater part of the coalfield, which has an area of 192 square miles.*

Neither is the great extension of single beds confined to those containing coal, but is found wherever there are beds of a sufficiently remarkable character to be noticed and recognised. A little bed called the Bone-bed, from its containing peculiar fragments of fossil bones, which lies just at the top of the New Red Sandstone of the south of England, is found both at Axmouth in Devonshire, and at Westbury and Aust in Gloucestershire—places fully sixty miles apart—the bed itself never being more than two or three feet thick, and frequently only as many inches. It was even stated by Mr. Strickland, that he had identified this same bed in the form of a white micaceous sandstone up to Defford in Worcestershire,† 104 miles from Axmouth, and at Golden Cliff and St. Hilary in Glamorganshire. Similarly, a bone-bed at the top of the Ludlow rock, never more than a foot thick, and frequently only one or two inches, has been traced at intervals over a space of forty-five miles from Pyrton Passage to the banks of the Teme near Ludlow. I have myself observed in the south of Ireland a bed of peculiar quartzose conglomerate, usually about a foot thick, in the middle of the Lower limestone shale at several places in the counties of Cork and Waterford, which show that it must have spread originally over an area of at least 300 square miles.

Whether these beds be absolutely continuous or not over all the intervening spaces, these facts are sufficient to prove the uniformity of conditions over very large areas, so that, wherever deposition took place, it was of precisely the same character. In the case of the bone-beds mentioned above, the conditions under which they were deposited seem to have been so very peculiar that they may perhaps be looked upon as exceptions rather than as examples of a rule. It is useful, however, sometimes to know what is possible as well as what commonly occurs; nor, perhaps, would such apparent exceptions be found to be very uncommon, if it were more often possible to trace a single bed over the whole area which it occupies.

When from a single thin bed we come to the examination of a group of a few beds, the instances of mineral identity over very wide areas become still more frequent. This is especially observable when the group of beds is of a character quite different from the larger mass of rocks in which they lie; provided that difference points to a state of greater tranquillity or quietness of action during the time of deposition, as would a bed of clay occurring in a group of sandstone beds, or a bed of limestone or coal occurring in others having a purely mechanical origin.

We may take, as an example, what is called the Bala limestone in North Wales. This is a little group of a few beds, rarely exceeding twenty feet in thickness, lying in a series of grey slaty rocks several thousand feet in thickness. The lowest bed of the limestone is generally black and crystalline, over which are

* *Coalfields of Great Britain.*

† *Proceedings of the Geological Society of London*, vol. iii. pp. 585 and 732.

several beds of hard crystalline concretionary and nodular limestone of a grey colour, alternating with more shaly or slaty beds. These contain small black phosphatic nodules, possibly of a coprolitic origin.* The softer argillaceous bands wear away more rapidly than the crystalline layers, which accordingly stand out in relief like a cornice moulding. By these characters the Bala limestone may often be perceived at the distance of half-a-mile on the side of a hill, and distinguished from the rocks of hard gritty slate above and below it. It extends from near Dinas Mowddwy on the south, to Cader Dinmael on the north, a distance of 22 miles, and from near Llanrhaidr yn Mochnant on the east, to the valley of Penmachno on the west, a distance of 24 miles; thus occupying an area of 400 or 500 square miles at least. It probably was once much more extensive; because, though we reach its apparent original termination in one direction near Dinas Mowddwy, where it dwindles to a thickness of two or three feet, in others its present "outcrop" shows no symptom of diminution of thickness or other sign of original termination.

On the other hand, some beds, even of a considerable thickness, have a remarkably small extension, being mere cakes, thick in the middle, and thinning out rapidly in every direction. This happens sometimes with all kinds of aqueous rocks; but is the more usual characteristic of the coarser mechanically-formed rocks, being more common in sandstones than in clays and shales, and more frequent in conglomerates than in sandstones. Beds of sandstone in the coal districts are sometimes found to thicken or thin out very rapidly. This is easily observable where sandstone beds are known to the colliers by specific names, and where the coal-pits are near together. The miners are occasionally thrown out in their calculations as to the depth at which particular coals will be found by these irregularities, which are sometimes so great and rapid as to be called "faults" by men not accustomed to precision in the terms they use. Such an instance occurs near Wednesbury, in South Staffordshire, where a bed of sandstone known by the name of the "New Mine rock" thickens out from nine feet to seventy-eight feet in the course of a few yards' horizontal distance. In other parts of the district this sandstone varies from fifteen to sixty feet, and in some places is entirely wanting.

In examining sandstones and conglomerates, the conglomerates or old gravel-beds are often found to be very partial and irregular, forming steep-sided banks and mounds enveloped in sand. In these cases, although it was obviously a work of time for the pebbles to have been ground down from their original large and angular condition to their present small rounded form, and although we may very well suppose them to have been washed about from place to place, and thus to have eventually travelled far from their original site, yet their final deposition in the place where we now find them was probably a rather rapid action. Conglomerates, then, may be quoted as examples either of the *length* of time required for their formation or of its *shortness*, according as we look to the *preparation* of their materials or the actual *deposition* of them.

Relation between the Extent and the Composition of a Bed.—It may be stated as a general rule, that the finer the materials of which a bed is composed, the wider is its area and the more equable its thickness, and the rule holds equally good for groups of beds. In a group

* A "coprolite" is the petrified dropping of some animal.

of beds made up of alternations of fine-grained and coarse materials, the variations in thickness in different parts of its area are generally due to the changes that take place in the coarser beds. In other words, the extent and equability of beds is generally in direct relation with the low specific gravity of their materials, or at least with their capacity for floating, those which sank most slowly being most widely and equably diffused through the water, and *vice versâ.*

A most remarkable example of the above rule is afforded us in the South Staffordshire coalfield, where a group of "Coal-measures" composed of alternations of clays, sandstones, and coals, which at Essington is between 300 and 400 feet in thickness, thins out towards the south, by the gradual dying away of the shales and sandstones, so that in the space of five or six miles the different beds of coal come to rest directly one upon the other, and are continued for ten miles at least towards the south as a compound seam of coal, thirty feet thick, with but a few shaly partings between the beds.*

The principal varieties of stratified rock are usually found in beds which are thinner, more extensive, and more equable, in the following order :—1. Conglomerates, the thickest, most irregular, and occupying the smallest area ; 2. Sandstone ; 3. Clay or Shale ; 4. Limestone ; 5. Coal, the thinnest, most regular, and most widely spread.

Irregular and Oblique Lamination and Stratification, *sometimes called* **"False-Bedding."**—In shales the laminæ are remarkably thin and regular, all parallel to each other, and parallel also to the planes

Fig. 26.

of stratification. In many fine-grained, and in some coarse-grained sandstones, this regularity and parallelism likewise prevails. In other

* *Mems. Geol. Survey*, S. Staff. Coalfield, 2d ed.

sandstones, however, great irregularity is observable in the laminæ of which the beds are made up, the layers of different-coloured or different-sized grains being oblique to the planes of stratification, and various sets of layers lying sometimes at various angles and inclining in different directions in the same bed, as in Fig. 26, which is taken from a sketch made on the coast of Waterford.

This structure is a proof of frequent change of direction, and probably of strength, in the currents which brought the sand into the water. If we suppose a current of water running over a surface which ends in a slope, as at *a* in Fig. 27, it is clear that any sand which is being drifted along the bottom from *b*, will, on reaching *a*, roll down into the comparatively still water of the deeper part, and remain there probably undisturbed. Layer after layer of sand may thus be deposited in an inclined position according to the slope of the bank.* On the other hand, if any obstacle arrests the sand which is being drifted along the bottom of any water, some of it will be piled up into a heap, and a bank will be then formed having laminæ more or less inclined. If the current shifts its direction, another bank may be formed, with its laminæ inclined at a different angle or in a different direction. Moreover, after one bank has been formed, a subsequent change in the velocity or the direction of the moving water may cut off and remove a portion of it, or excavate a channel through it, and this hollow or fresh surface may be again filled up or covered over by layers having a different form from the first. In this way water subject to changes of current, especially shallow water full of eddies, will throw down or heap up materials in a very confused and irregular manner.

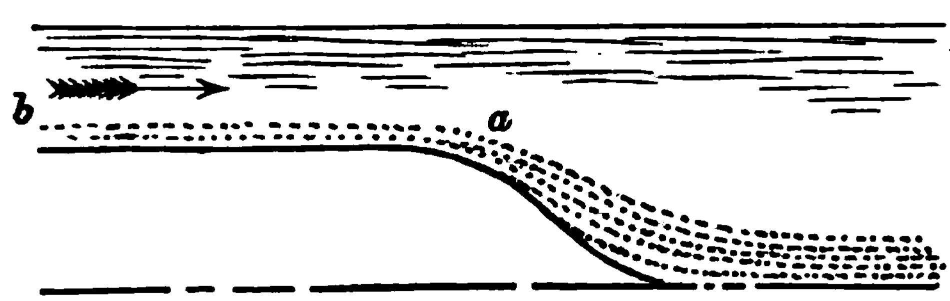

Fig. 27.

Oblique lamination of beds is carried out sometimes to such an extent as to produce several beds, sometimes of no slight thickness, which lie obliquely to those above and below them. Instances of this were observed and described by Mr. G. V. Du Noyer in the Dingle promontory, on the west coast of Ireland. He pointed out to me such series of beds lying obliquely to each other, both in the cliffs and in the shores exposed at low water. I have also observed a similar case

* A very pretty little machine has been invented by Mr. Sorby for producing this oblique lamination. Sand poured into a small trough is carried forwards by means of a screw, and falling down into a narrow space between a board and a sheet of glass, arranges itself in inclined layers according to the rapidity with which the screw is worked and the angle at which the instrument is held.

in South Staffordshire, where, over a space at least a quarter of a mile across, quarries were opened showing beds of sandstone inclined at an angle of 30°, while a horizontal bed of coal stretched, a little way below, over the whole area.

Rolls, Swells, Horses' Backs.—It is a modification of the same action probably which has produced what are called "rolls," "swells," or "horses' backs," in the Coal Measures, and probably in other rocks where they remain less noticed. A long ridge, and sometimes one or two parallel ridges, of clay or shale are occasionally found rising from the floor through one or more beds of coal, "cutting them out" for a certain distance, to use the miners' terms. The crest of such a ridge is sometimes eight feet above the floor of the coal, with a very gentle inclination on either side, the beds of coal ending smoothly and gradually against it.* Its formation was obviously anterior to that of the coals which it "cuts out;" those coals and the "swell" itself being regularly covered either by a higher bed of coal, or by the "roof" of the seam, without any interruption or disturbance. The swells are sometimes 200 or 300 yards long, and 10 or 12 yards wide at the base. (See Fig. 28).

Fig. 28.

In this Fig. *a* is black clunch containing balls of ironstone; *b b* beds of coal.

Current-Mark or Ripple.—Another effect of current is to produce a "ripple" or "current-mark" on the surface of a bed of sandstone or sandy shale. This rippled surface is exactly the same as that which is seen on the sands of the sea-shore when left dry by the tide, and which may occasionally be seen on the sandy bottom of a brook or any other running water. It may be observed also sometimes on sand-hills on dry land, where it is produced by the drifting action of the wind. Both wind and water, as they roll before them the little grains of sand, tend to pile them into small ridges, which are perpetually advancing one on the other, in consequence of the little grains of sand being successively pushed up the windward or weather side of each ridge, and then rolling over and resting on the lee or sheltered side.

It is produced on the sea-beach, not in consequence of the ripple of the wave impressing its own form on the sand below, which would be an impossibility, but because of the moving current of water as the tide

* See *Mems. Geol. Survey*, S. Staffordshire, second edition.

advances or recedes. Wind moving over the surface of water causes a ripple on that surface. Wind or water moving over the surface of fine incoherent sand causes a similar ripple upon it. The ripple on the surface of a liquid is of course momentary. The ripple on the surface of sand, however, remains permanent unless obliterated by some subsequent force. If the rippled surface be covered by a film of clay, or if it acquire some degree of consolidation before another layer of sand be drifted over it, it may remain fixed for ever. In fine-grained sandstones, it is not unusual to find many successive rippled surfaces, one under the other, at spaces of some inches or some feet apart vertically, the direction of the ripples sometimes varying very considerably on the different surfaces. It is clear that the under surface of the layer of sand which is deposited upon a rippled surface will itself take a cast of the rippled form. It is sometimes not easy to determine, in detached portions of such beds, which was the original rippled surface and which is its cast. Very often, however, this can be determined by their difference in form, the ridges being broad and equable, while the intermediate furrows have a little channel, the cast of which makes a sharp little crest, such as could not be formed on the summit of the ridge. This feature is sometimes of use in examining highly inclined, perpendicular, or inverted beds, as helping us to decide which was the upper surface of the beds in their original undisturbed position.

The existence of a rippled surface is no evidence of itself as to the depth of the water in which it was formed. A current of water of any depth whatever, which pushes grains of sand along the bottom, may produce a rippled surface on that sand. The ripple on the surface of water, or on that of dry sand-hills, is produced at the bottom of the atmosphere, and if the lower stratum of deep water moved in like manner, it would produce a similar effect. Rippled surfaces will, however, be more frequently produced at the bottom of shallow than of deep water, because the requisite currents are more frequent in the former than in the latter.

The size of the ripple, or the distance from crest to crest of the ridges, varies from half-an-inch to eight or ten inches, with a proportionate variation in the depth of the hollows between them. Sandstones of all ages, from the oldest known rocks to the most modern, have occasionally rippled surfaces. Magnificent examples are sometimes shown in the cliffs of the south-west coast of Ireland, where highly inclined beds are seen bared in the face of the cliffs at the sides of small bays, exposing most beautifully rippled surfaces over an area one or two hundred feet in diameter.

In places where the current was troubled, a modification of these rippled surfaces is sometimes produced, the bed being irregularly mammillated on its surface, which is pretty equally, although irregularly,

divided into small hollows and protuberances of a few inches diameter. This surface structure may be seen in process of production now, on shores where spaces of sand are enclosed by rocks, so that as the tide falls it is made to run in different directions among the rock-channels; but it would probably be caused at any depth at which a current could be similarly troubled and confused. It is not unfrequently seen among gritstones, even those of the very oldest rocks. It might be called "dimpled current-mark."

Mr. Sorby has shown that inferences may be drawn from the examination of these "current-marks" as to the strength and direction of the currents that caused them, and that we may thus reason back to some conclusions as to the physical geography of particular districts in former geological periods.* From these, as from other physical structures in rocks, we infer that the strength, velocity, and mode of action of moving water in the old geological periods were of the same kind and intensity as those with which we are familiar at the present day.

Contemporaneous Erosion and Filling up.—Stratified rocks sometimes occur in such a way with respect to each other as to show that a bed, not only of sand, but of clay, coal, or other soft rock, after being formed, has had channels or hollows cut into it by currents of water, and these hollows have been filled up by a part of the bed next deposited. In Fig. 29, taken from a road-cutting in the New Red Sandstone

Fig. 29.

at Rudge Heath, near Wolverhampton, 1 was a bed of red and white marl or clay; 2, a chocolate-brown sandstone with irregular beds and patches of marl; 3, a bed of red marl, like 1, but which seemed at one time to have been thicker than now, and to have had some part of its upper surface carried off before the deposition of 4, which was a brown sandstone, that in like manner seemed to have had its upper surface eroded and the hollows filled up by the deposition of 5, which was a mottled, red brown and white, calcareous sandstone, or cornstone.

* He has more recently shown the existence of structures resembling ordinary and dimpled "current-marks" on the surface of beds of mica-schist in Scotland (*Q. G. S. L.*, vol. xix. p. 401), showing that these mica-schists were originally beds of silt.

This erosion sometimes affects even a small group of beds. In the tertiary beds near Paris, which are believed to have been deposited in a shallow bay or gulf, receiving rivers, and therefore traversed by currents, this structure is frequent. Two remarkable examples were observable in the large excavation near the terminus of the Rouen railway in the year 1853. In a cliff about 40 feet high in the fresh-water limestone formation, called the Calcaire St. Ouen, I saw two trough-like hollows about 50 yards apart; the beds previously formed having been excavated for a depth of 20 feet and a width of 15, and the hollows thus formed being filled up by irregular meniscus-shaped * expansions of the upper beds. (See Fig. 30.)

Fig. 30.

Hollow of erosion in tertiary rocks near Paris, filled up by thickening of the subsequently formed beds.

Similar trough-like hollows are met with in coal-mining, the coal being eaten away, and the hollows filled up by the matter which composes its roof, such as clay, shale, or sandstone. Mr. Buddle has described very fully one met with in the Forest of Dean, where the miners gave the name of "the horse" to the stuff which thus seemed to come down and press out the coal. This trough was found to branch when traced over a considerable area, and to assume all the appearance of having been formed by a little stream with small tributaries falling into it; the channels of the stream being afterwards filled up by the subsequently deposited materials that were spread over the whole coal.†

Another modification of this erosive action is represented in Fig. 31, taken from a sketch made in a quarry in the neighbourhood of Hobart Town, Tasmania, where a bed of soft brown unctuous clay, about a foot thick (*b*), lying between two beds of hard white sandstone (*a* and *d*), suddenly ended, and its place was occupied by sandstone (*c*) similar in character to the beds above and below it. We must in this case suppose that after the formation of the bed of sandstone (*a a*), a bed of clay (*b*) was deposited over a certain portion of the area, and that then a current of water wore back the little bed of clay, so as to form a small cliff or step, and afterwards deposited the sand (*c*) against it, as represented in the diagram. The two beds, thus exactly on the same level, but *not exactly contemporaneous*, were finally covered by the bed of sandstone (*d d*), which spread equally over both of them. Such facts give us farther proof of the length of the intervals which may elapse between the formation of two beds, such as *a* and *d*, and also caution us not

* A meniscus is a lens concave on one surface, and convex on the other.

† *Trans. Geol. Soc. Lond.*, vol. vi. n. s.

in all cases to infer strict synchronism from the fact of beds occupying the same geological horizon.

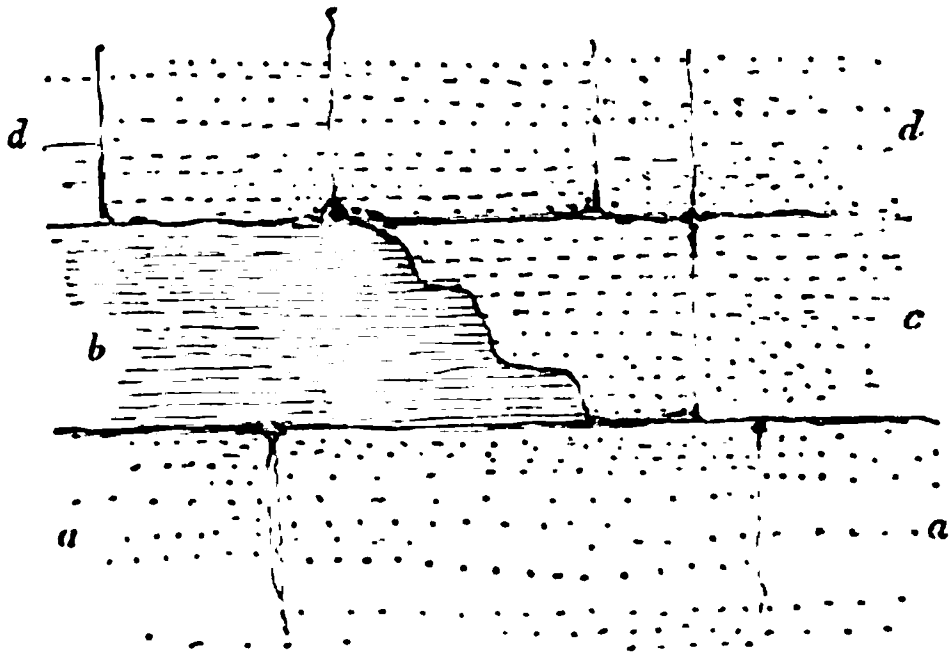

Fig. 31.

Eroded termination of bed of clay, with sandstone formed against it (Hobart Town, Tasmania).

Contemporaneity of Beds on same Horizon.—If a group of beds, whether large or small, have the arrangement shown in Fig. 32, the

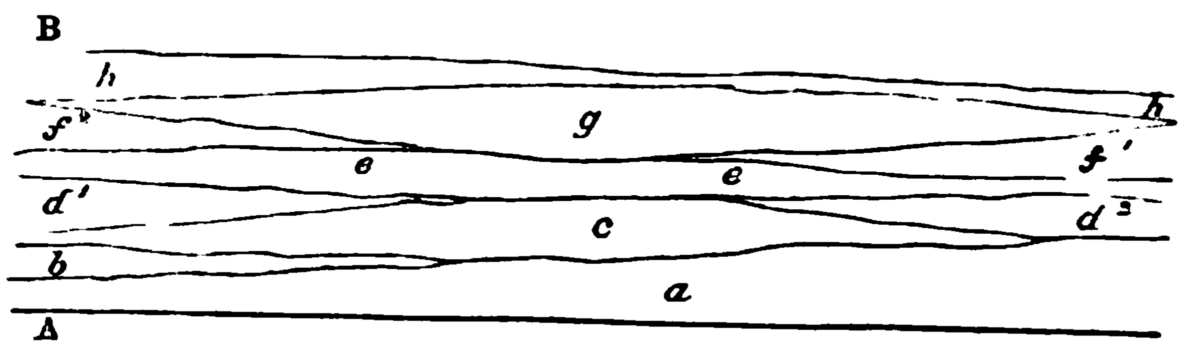

Fig. 32.

order of the formation of the beds is clear enough as regards *a*, *b*, and *c*; but d^1 d^2 may either have been deposited contemporaneously, or one before the other; *e* is clearly subsequent to them both; but the relative age of f^1 and f^2 is uncertain, while there is no doubt about that of *g* and *h*. If we wished to estimate the whole time consumed in the formation of such a set of beds, it would be obviously wrong merely to take their mean thickness, as shown at A B, for the measure of that time. The whole thickness of *a* had been deposited before *b* had been begun, and both were complete before *c* was formed. If, therefore, we assume thickness, or quantity of material deposited, as the measure of time occupied in deposition, it is clear that we should add together the maxima of *a*, *b*, *c*, and not take their mean; and in doing this, we should feel some doubt as to whether we ought not to reckon d^1 and d^2, and similarly f^1 and f^2, as two consecutive beds, instead of supposing them to have been formed at the same time.

The more carefully we study the stratified rocks, the more extensive become the periods of time we have to allow for their formation, and

the more numerous and longer are the intervals of non-deposition that occur to us.

Interstratification, Association, and Alternation of Beds.—No general rule can be laid down as to the association of different kinds of beds with one another. Limestones, sandstones, and clays, occur either in separate groups, or interstratified one with the other in every imaginable variety of disposition. We have sometimes a series of beds, many hundreds of feet in aggregate thickness, of nearly pure limestone, with scarcely a single seam of clay or sand, even so much as an inch thick. Instances of this are shown in the Chalk of the south-east of England, and the Carboniferous Limestone of Derbyshire, and of large portions of Ireland.

In the case of the Chalk, there is in some places a thickness of as much as 1000 feet of soft, almost powdery, and nearly pure, white carbonate of lime, that looks more like an artificial than a natural product. Its stratification even is occasionally indistinct, as if there had been almost a continuous deposit of this material with scarcely any interruption, though this is probably the result of the comparatively slight consolidation of the rock rather than of its rapid accumulation.

In the district called Burren, in County Clare, there are hills more than 1000 feet high, exposing slightly inclined beds of Carboniferous limestone, bare of soil or any other covering, from their summits down to the sea. A thickness of 1400 feet, at least, is thus shown without a trace of any other bed than grey limestone, except occasional nodules or thin seams of chert.

Series of beds of sandstone, almost entirely devoid of calcareous or argillaceous matter, and having a total thickness of many hundred feet, likewise frequently occur. Old gravel-beds, now compacted into conglomerate, are often associated with these; and the sandstones exhibit every variety of texture, from lines of small pebbles to the finest possible grains. In such masses of sandstone it is rare to find any foreign bodies, and mineral concretions or chemical deposits hardly ever occur in them. Groups of beds of almost pure clay also occur, making up a total thickness of several hundred feet, with hardly a single bed of sandstone or limestone to be found in them.

While cases of this accumulation of some particular kind of matter, of great thickness, are by no means rare, it is perhaps more usual to find different beds of rock alternating one with the other, sometimes so interstratified that there is never a greater accumulation than twenty or thirty feet of any one sort without others interposed between them. Beds of limestone are frequently separated by beds of clay or shale, which is most commonly black or brown. These clays are themselves sometimes calcareous, and there seems occasionally to have been such an equal mingling of the two kinds of matter, that it is hard to say whether it would be most proper to call the rock an indurated calcareous clay or an argillaceous limestone. Such are some of the beds known as Calp shale or Calp limestone in the neighbourhood of Dublin. Beds of sandstone, again, often alternate with such shales, so that we get a series of beds consisting of alternations of all these kinds. Beds of limestone sometimes alternate with sandstones, some of which may likewise be

calcareous; but it is more rare to find pure limestone and pure sandstone interstratified with each other, than to have clayey beds alternating with either or with both. Speaking generally, indeed, we find, in examining the vertical succession of beds of rock, an approach to the same kind of passage that we sometimes perceive in their lateral extension. Beds of very fine and very coarse materials rarely rest directly one upon the other. Conglomerates are generally covered and underlaid by sandstones, and not by clays or shales. Coarse sandstone, in the same way, has usually a bed of finer sandstone either above or below, before shale or clay occurs.

The transition from the conditions favourable to the deposition of one kind of rock to those conducive to another has generally been gradual. The tranquil water of the open sea, which seems to be the general producer of limestone, becomes first invaded by gentle currents, bringing in finely-suspended mud, before it is traversed by those of sufficient strength to carry out the coarser material of sand. Not unfrequently, however, alternations of finer and coarser grained laminæ occur even in the same bed of shale or sandstone, proving that the bed was formed by a succession of actions, and by as many different deliveries of matter into the water as there are sets of alternations.

It will be well, perhaps, to give here an instance of alternation of beds, taken from actual observation and measurement. The following is from a table by Professor Phillips:—*

No.		Beds.
21.	Beds of sandstone, called Millstone Grit, together	87
20.	Beds of shale, taken together	30
19.	A bed of limestone	2
18.	Beds of shale	18
17.	A bed of limestone	3
16.	Beds of shale	6
15.	A bed of limestone	3
14.	Beds of shale, together	25
13.	Flinty chert (a compact siliceous rock)	16
12.	A bed of shale	1
11.	Crow chert. (Crow is a local term)	6
10.	Shales	9
9.	Second crow chert	12
8.	Crow limestones (probably in several beds)	12
7.	Sandstone or gritstone	6
6.	Coal	1
5.	Sandstone or gritstone	7
4.	Shales	8
3.	Gritstone in several beds	88
2.	Girdles (a kind of sandstone)	10
1.	Shales	18
		368

* *Geology of Yorkshire*, vol. ii. p. 66. In all tabular lists of beds or formations in this work, the series will be arranged on the page in their order of superposition, but they will be numbered in order of age, beginning with the lowest as the oldest or first formed.

		Ft.	In.
11	11. Earthy rotten shale, with a thin hard band . .	2	7
10	10. Grey crystalline crinoidal limestone . . .	3	4
9	9. Soft brown earthy shale, with abundance of fossils and many irregular layers of black chert . . .	11	6
8	8. Hard grey shale, with encrinites and shells . .	0	9
7	7. Grey compact limestone .	3	6
6	6. Do. with layer of black chert nodules	1	4
5	5. Thin irregularly bedded limestone, with shale at top .	1	9
4	4. Compact limestone . .	0	9
3	3. Light-grey compact limestone	4	8
2	2. Black chert layers in hard black shale . . .	1	0
1	1. Grey compact limestone, forming floor of quarry . .	1	0
		32	2

Fig. [illegible].

These beds are grouped together, with some others, under the name of the "Millstone grit series," by Professor Phillips, it being often necessary to supply some one designation to a complicated series consisting of all kinds of rock. In sinking coal-pits, many alternations of arenaceous and argillaceous rocks, the latter sometimes containing ironstones, are almost invariably met with, beds of coal of different thickness and quality occurring here and there in the series.

Numerous examples of vertical sections of coal-pits are given in the publications of the Geological Survey, as well as in other works, showing sometimes the existence of several hundreds of alternations of different beds with a total thickness of some thousands of feet.

It is to be specially noted, as regards the occurrence of coal, that it almost invariably rests on a fine argillaceous bed, often what is called "fireclay." This fact is familiar even to the miners, so that it has received the name of "underclay" in the South Welsh district, and in others, as in the South of Ireland, is called "coal *seat.*" The general order of superposition (or of time of formation, for these are convertible terms), is, 1. Sandstone; 2. Clay; 3. Coal; 4. Clay. If we disregard the minor alternations, we should see this rule carried out in almost all sections of Coal-measures, the clay above the coal (the roof) being generally thinner and stronger (more shaly) than that immediately below. In some few instances the coal seat is arenaceous, and still more frequently a sandstone or "rock" roof may be found.

The section (Fig. 33), supplied by Mr. G. V. Du Noyer, was taken in a quarry near Old Leighlin, County Carlow, where the top beds of the Upper Carboniferous limestone of Ireland pass into the lower Coal-measures.

Lateral Change in the Lithological Characters of Beds.—It has been already shown that every bed must necessarily thin out and terminate somewhere on all sides, and it has also been shown that beds lying side by side on the same horizon are often different in lithological composition. What is true of one bed may be true of sets of beds, so that, while the whole of a set of one kind of beds may in one direction be replaced by a set of a similar kind, in another the replacing set may be of a totally different kind of rock. We might, for instance, in one locality, have a series of limestones, resting one upon the other, without the intervention of any other beds. As we traced this group across a country, we should perhaps find that little "partings" of shale began to make their appearance between some of the beds of limestone, and that as we proceeded these shales became thicker and more numerous, while the limestones became thinner in proportion. Some of the limestones would perhaps then altogether disappear, and the shales themselves would be partially replaced by beds of sandstone, until at length we should find our series consist almost entirely of sandstones and shales, with only one or two very subordinate beds of limestone perhaps, to represent the purely calcareous group with which we commenced. The diagram, Fig. 34, gives a rough representation of this lateral change, but requires to be drawn out to twenty or thirty times its length before it could be taken as a proximate delineation of the facts as they occur in nature.

The scale upon which these lateral changes of character are carried out is altogether indefinite. We see it sometimes take place with respect to a small group of beds within the limits of a single quarry; in other

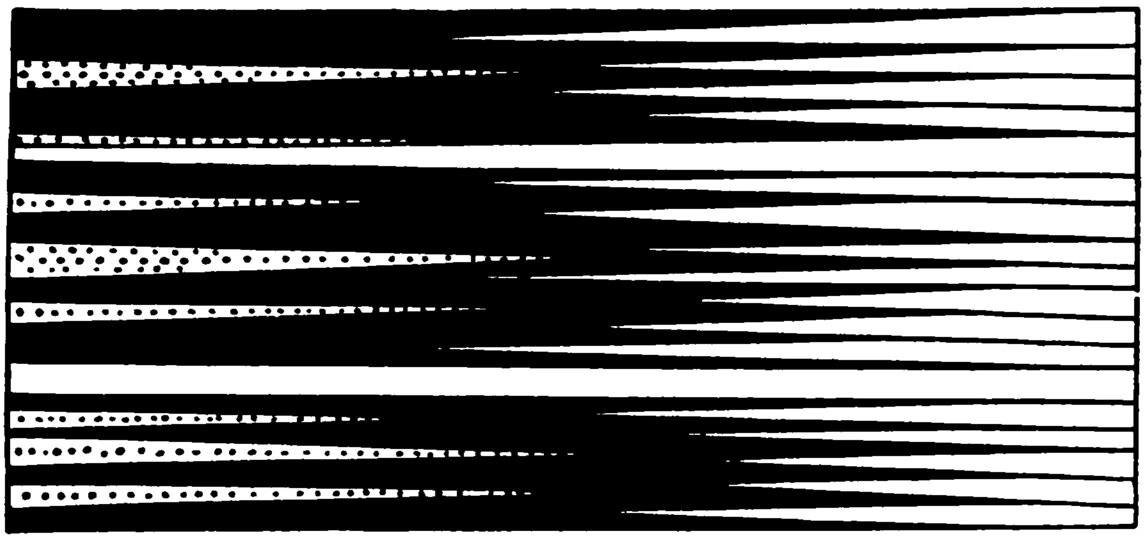

Fig. 34.
In this diagram the white bands are meant for limestones, the black for shales, and the dotted for sandstones.

cases, a distance of a few hundred yards or a few miles is requisite before the alteration is apparent. Some groups of beds, indeed, preserve their mineral characters but little altered over whole countries or across whole continents. Still, judging from what we know, we must always hold ourselves prepared for change even in the rocks that seem most constant in their characters; and as a matter of fact, we know of no one group of aqueous rocks that preserves the same mineral characters in all parts of the earth.

We have many excellent examples of these lateral changes in groups of strata within the limits of the British islands. We can perhaps hardly instance a more characteristic one than that afforded by the group of beds known as the Lower Oolites, which are readily traceable in one continuous ridge from Somerset, through Gloucestershire and the centre of England, to the Humber, and reappear again as high ground in the north of Yorkshire. These beds repose throughout upon some dark shales and clays known as the Lias, and are throughout covered by a thick mass of clay called the Oxford Clay, and appear everywhere to form a continuous series of beds. The Lower Oolites, which thus lie between these two great clay deposits, consist, in the south of England, very largely of oolitic limestones, and it was here they received their name of "The Oolite," while in Yorkshire the limestones are replaced by sandstones and clays, with beds of coal, and the thickness is considerably greater than in the south.* The section of the two groups may be described as follows:—

* The Gloucestershire section is taken from Conybeare and Phillips' *Geology of England and Wales*, and that of Yorkshire from Professor Phillips' *Geology of Yorkshire*, with which has been compared his paper on the Oolite and Ironstone series of Yorkshire in the *Journal of the Geological Society of London*, vol. xiv. p. 84.

GLOUCESTERSHIRE, ETC.

			Feet.
	Oxford clay.		
5.	Cornbrash . . .		16
4.	Clay . . .	11	91
	Calcareo-siliceous sand	10	
	Forest marble . .	18	
	Sand . . .	2	
	Clay . . .	50	
3.	Great oolite . . .		130
2.	Blue Clay . .	14	122
	Fuller's earth . .	8	
	Bastard Fuller's earth, with a band of shelly sandstone . .	100	
1.	Inferior oolite .	30	80
	Calcareous sand .	50	
	Total . .		439
	Lias.		

YORKSHIRE.

		Feet.
	Oxford clay.	
5.	Cornbrash	5
4.	Sandstones and shales, with ironstone and coal .	190
3.	Gristhorpe oolite . .	15
2.	Sandstones and shales, with ironstone and coal .	450
1.	Yellow and grey micaceous and ferruginous sandstone . . .	70
	Total . .	730
	Lias.	

Still greater changes take place in the lateral extension of the larger group of rocks known as the Carboniferous formation, when traced from Devonshire and Cornwall through the centre of England into Scotland, or from the south to the north of Ireland, as will be seen farther on when we come to describe the typical rocks of that formation.

If the diagram, Fig. 34, be supposed to represent a series, not of individual beds, but a series of formations, so that each of the divisions be supposed to be many hundred feet thick and many miles in extent, they will equally represent, in a rude manner, the way in which the stratified crust of the earth is made up. No single bed, no group of beds, no series of beds, no formation, is of unlimited extent. They all come to an end somewhere; having, at their first formation, by the very conditions of their production, gradually diminished and died away in every direction from some local centre or centres of deposition.

Nomenclature of Groups of Beds.—It may be asked here, if the lithological characters of groups of beds be so variable, how is it that geologists identify rocks by the same designation all over the globe? How is it that we speak of Silurian, or Cretaceous, or Carboniferous rocks in Australia, in Africa, in Asia, and in America, as well as in Europe? The answer is, that geological terms, when applied to rocks in this sense, have a purely chronological signification; they refer to periods of time; they mean that the rocks called Silurian, for instance, in Australia, were formed during the same great period of the world's history, as those which are called Silurian in Siluria.* How this is proved will be shown farther on; but it is necessary here to

* Not that strict contemporaneity is affirmed, but that the Silurian rocks were formed during the same relative period in the history of the development of life in one region as in another, though the period may have been somewhat earlier or later in different countries.

warn the student of this meaning, in order that he may not form erroneous notions.

Earthy depositions are now taking place in Bass' Straits, for instance, as well as in the English Channel: in like manner, mineral matter was deposited contemporaneously here and there upon the earth at all periods of its history since land and water came into existence upon it. If we can find out those rocks which were simultaneously formed, we may designate them by a common name, simply to point out the fact of this similarity in age, without inferring that they were ever parts of a continuous mass, or were formed of the same materials, or were produced exactly in the same way, or under precisely similar conditions.

Whatever may be the origin of the name we adopt, whether it be that of their lithological character at the locality where they were first described, or whether it be derived from some mineral substance contained in them, or from the place where they are best seen, or any other source, we must be careful to recollect that the name will usually be a mere name and not a description, since its original meaning can hardly ever be universally applicable. Just as we find Mr. White and Mr. Black, Mr. Long and Mr. Short, with persons the very reverse, perhaps, of what their names would imply, so we may in geology have the name of "red" or "green sandstone" affixed to rocks which in some places are neither red nor green, nor even sandstone, so we may have "coal-measures" which in some places contain no coal, and "chalk" or "cretaceous" rocks which, in some parts of the world, consist of black marble, of brown sandstones, or of dark clay-slate.

Lateral and Vertical Changes in Groups of Beds, the natural result of their Mode of Formation.—The apparent contradiction that arises between the signification of the name of a group of beds and their lithological character is often a difficulty in the way of a beginner; but when he comes to reason on the modes of formation of stratified rocks, he finds it much easier to explain their variable character by reference to the present course of nature, than he would to account for their invariability, if each formation retained everywhere the same lithological character.*

* See the remarks in a subsequent chapter on Sea-bottoms, especially with reference to the Atlantic and Pacific Oceans.

CHAPTER VII.

JOINTS, FORMATION OF ROCK-BLOCKS.

We could not long study the stratification of aqueous rocks, without being struck by the occurrence of other planes of division, which cut the first at various angles, and assist them in dividing the rocks into regular or irregular blocks. We should, indeed, very soon perceive that *all* rocks, stratified or unstratified, igneous, aqueous, and metamorphic, are traversed by numerous planes of division of this kind. They may be seen in any quarry, or in any natural or artificial excavation in any solid rock, traversing the rock in various directions, and separating it into blocks of various shapes and sizes. These divisional planes are called JOINTS.*

Without natural joints the quarrying of stratified rocks would be very difficult, and that of unstratified rocks almost impossible. If beds of sandstone or limestone were undivided by natural joints, each block would have to be cut or split by artificial means on every side from the rest of the bed; but in rocks, such as granite or greenstone, which have no beds, the blocks would not only have to be cut away on each side, but *underneath* also. It would obviously be a most difficult if not impossible task to *dig out* a large block of granite from the midst of a solid mass untraversed by any natural planes of division of any kind.

Cuboidal or Quadrangular Joints.

For the production of natural blocks of rock there must clearly be, *at least*, two sets of joints in stratified, and three sets in unstratified rocks, each set more or less nearly at right angles to each other. (See Figs. 35 and 36.) If we compare a set of stratified rocks to a pile of slices of bread, it is clear that to divide these into square pieces, we must cut them in two ways, lengthwise and across. The unstratified rocks, however, would resemble the whole loaf, which we must cut at least in three directions in order to divide it into square pieces, first horizontally into slices, and then lengthwise and across. In addition to these fewest possible sets of joints in the two kinds of rock, there are in reality others in various and irregular directions; but inasmuch as three planes

* This term is known to most quarrymen, though they often distinguish them as "backs" and "ends," or "backs" and "cutters," and often confound planes of stratification with them. In Cornwall it appears that the word "seam" is often used to denote a joint.

of separation more or less nearly at right angles to each other are the essential conditions for the separation of rock into blocks, and as three equidistant planes at right angles to each other would form cubes, we may speak of joints thus forming quadrangular blocks as *cuboidal* or *quadrangular* joints, to distinguish them from those which produce prisms, and we may look upon three-cornered and irregular blocks as merely portions of cuboidal ones.

A sketch taken by Mr. G. V. Du Noyer, in a limestone quarry near Mallow, is given in Fig. 85. The parallel lines, nearly horizontal but inclining gently from

Fig. 85.
Joints in Limestone. Quarry near Mallow, County Cork.

the spectator, are the planes of stratification, while the smooth nearly vertical surfaces, which form the face or wall of the quarry and bound the projecting corners

Fig. 86.
Joints in granite. Large quarries in Killiney Hill, near Dublin.

of rock, are the joint-planes. One set of these joints runs lengthwise through the quarry, and makes the successive surfaces on which the light falls; the other set

forms the dark surfaces which are at right angles to the light ones, and other joints belonging to this set are shown by the nearly vertical lines which are seen upon those light surfaces, those lines being the edges of joint-planes.

Fig. 36 is from a sketch taken by Mr. Du Noyer, in the large granite quarries from which the stone to form Kingston harbour was extracted. It will be at once apparent that this rock exhibits no regular beds. One set of parallel planes of division, highly inclined to the right, seems to prevail in one part of it, and another set, highly inclined to the left, in another part. These might at first, perhaps, be in each case taken for planes of stratification, and the pieces of rock between them be considered to be beds. They are, however, merely two sets of joints, and they are crossed by a third set producing the shaded faces of rock which front the spectator. In walking about the quarry each of these three sets of joints becomes most conspicuous, according to the point of view which may be taken; while they are sometimes all masked or obscured by a number of other irregular joints which cut the mass in many other directions.

Master Joints.—There is, indeed, in all rocks, whether aqueous or igneous, a distinction to be drawn between the "master joints," or those large planes of division which run regularly parallel to each other over large distances both in length and breadth, and the numerous smaller joints which often traverse the rock in all directions for short distances, and separate it into small angular fragments. This distinction is, however, one which it is often difficult to point out, since there are many joints of intermediate character. Sometimes, indeed, in aqueous rocks, the joints are so numerous, and cut the rocks in so many directions, that the original planes of stratification are altogether obscured by them, and it is impossible to say which are the planes of original separation between the beds, and which are those of subsequent origin. There are cases, on the other hand, of joints a few feet apart cutting in parallel lines through whole mountain masses, the space between two nearly adjacent joints being eroded into a deep fissure, so as to produce a more marked feature in the hills than their planes of stratification. Such remarkable joints are very strikingly exhibited in the mountain ground between Bantry and Kenmare bays, in the south-west of Ireland.

There is in some cases either great width between the planes of one particular set of joints, or one set is more or less completely absent, so that, in one direction, the rock is unbroken for considerable distances. This must be the case with the rocks from which the great monolithic pillars were extracted in the old Egyptian and other quarries. On the shores of Newfoundland there are large exposures of granite, in which only one set of perpendicular joints is apparent, and those having a width of several yards between them, and running parallel for considerable distances. Some of the rocks in India also yield large monoliths, in consequence of the absence of one set of joints, or the distance between them, so that various artificial means have to be adopted to split the rocks into blocks small enough for ordinary use. The beautiful red granite of the Island of Mull is likewise remarkable for the persistence and domi-

nation of its master joints, whence blocks of great length can be extracted entire.

While the surfaces of a block formed by the joints always approximate to planes when viewed on the large scale, they are nevertheless sometimes very uneven, and sometimes even curved. I observed in a limestone quarry near Foynes, a master joint that formed a surface as much curved as the side of a ship, only waving backwards and forwards in length, so as to curve now on the one side and now on the other of the perpendicular.

Open or Close Joints.—Joints are generally close, regular, and symmetrical, in proportion to the fineness of the grain and the compactness of the rock, being most irregular and uneven in coarse sandstones and conglomerates. The power of the force which produces them is, however, well shown in hard conglomerates, since pebbles of pure white quartz are often cut as clean through by the joints as the compacted sand in which they lie. In sandstones, joints are frequently open; in shales, they are closer, but more smooth and regular, being frequently perfect planes, with the sides of the blocks fitting close together. In limestones, there are both close and open joints; but the open joints have been widened by the action of acidulous water dissolving the rock on the sides of the joint planes. Great fissures are sometimes formed in this way; and this has doubtless been the origin of many of the caverns which occur so abundantly in limestone rocks.* In highly argillaceous limestones, however, the joints are often beautifully smooth, regular, and close.

Successive Formation of Joints.—In stratified rocks, it often seems as if each bed had a system of joints formed before the other was deposited upon it, inasmuch as the joints formed in one do not penetrate the other. There are, however, always other joints common to a whole set of beds, and produced apparently in the whole simultaneously. It is not uncommon for joints, in passing from one bed to another, to shift a little, or slightly change their angle. In such cases it may be doubtful whether a joint previously formed in the one bed may not have given rise to the formation, or at least have modified the position, of the other, in the bed above.

Joints in Burren, County Clare.—In the barony of Burren, in the northern part of the county of Clare, hills of limestone rise more than 1000 feet above the sea, with the beds almost horizontal, the summits of the hills and the terraces that sweep round their sides showing broad floors of bare rock over the whole country. The joints, which are very numerous and very regular, have been widened by the rain, so as to form superficial crevices, sometimes several inches in width and several feet in depth. The floors of limestone are cut by them into a number of separate blocks of quadrangular and triangular forms.

* This action will be described in the section on Geological Agencies.

The late Mr. F. J. Foot, of the Geological Survey, who examined this district, has given a detailed account of these joints.* The following figure (No. 37) is a reduced copy of a plan which he constructed of some of them as they showed themselves on the surface of a horizontal bed of limestone, several feet in thickness, and twelve or thirteen yards across. A very remarkable circumstance was the occurrence of two sets of joints running nearly N. and S., one a little to the E. of N., the other a little to the west of it, so as to produce large wedge-shaped blocks, several feet long, ending in angles sometimes as sharp as 5°. One of these is shown at the N.W. corner of the figure, but they were occasionally more numerous. Many of the joint-planes could be followed even for two or three hundred yards, but others sometimes ended abruptly, not only where crossed by another joint, but in the centre of a block of rock. Sometimes the neighbourhood of one joint-plane, or the space between two, if they happened to be within a yard or so of each other, exhibited a number of closely adjacent minor parallel joints not more than an inch or so apart, splitting the beds across into vertical slabs. It is probably to the weathering of the vertical slabs thus produced that the long parallel crevices are due which have been already mentioned as remarkable on the steep sides of the hills about Bantry Bay and other places. The union of square, sharply triangular, and curved-sided blocks, with deep fissures between them, the surfaces and edges of the blocks being curiously rounded and channelled by the rain into ornamental fret-work, as if the white limestone were melting ice, produces a most singular scene, to which beauty is added by the magnificent ferns and other plants growing in the crevices of the joints, which seem to act as natural conservatories to protect the vegetation from rough weather.

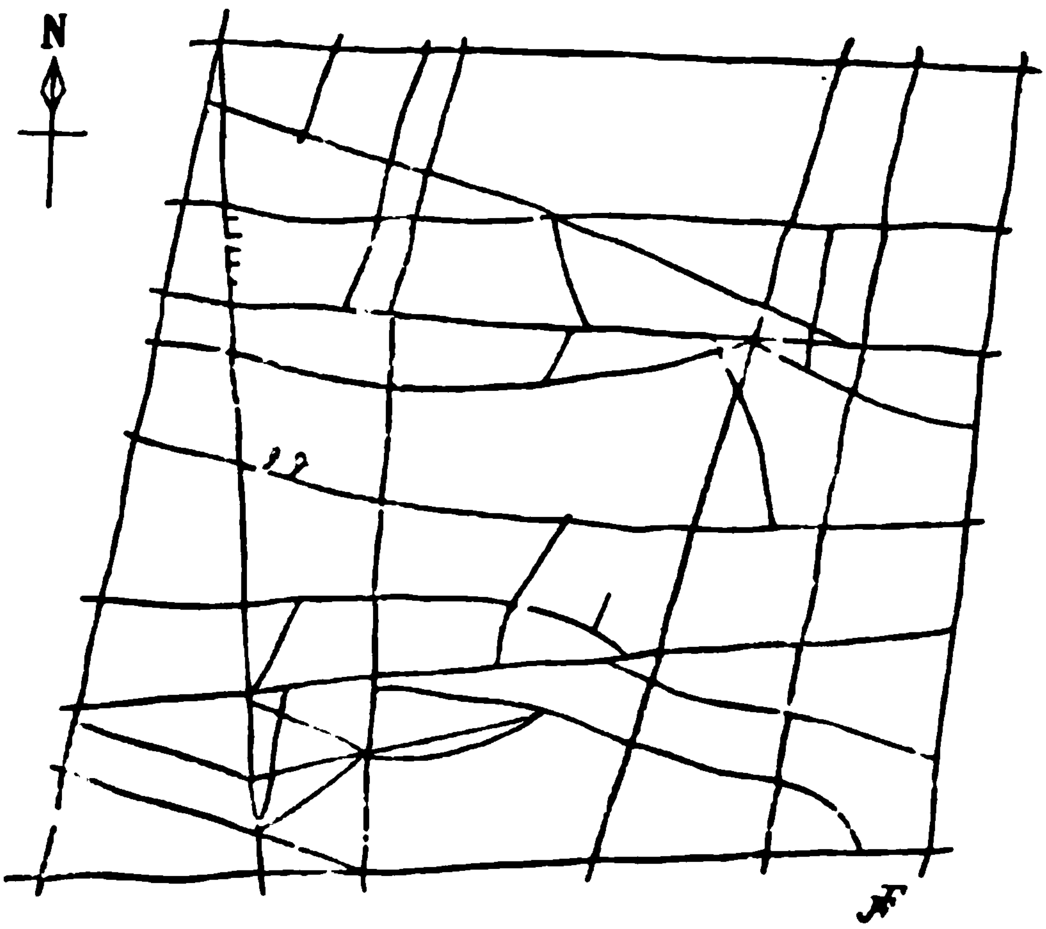

Fig. 37.

Face, Slyne, or Cleat in Coal.—Beds of coal exhibit not only large distant joints, like all other rocks, but a more minute structure dividing the mass of the coal into small cuboidal lumps. This structure may be observed in any lump of coal taken from the coal-hod, and if the student will take such a lump and place it on the table before him, he will at once have an excellent model of lamination, stratification, and jointing, as well as this other structure.

* See Explanation of Sheets 114, 122, and 123, of the Maps of the Geological Survey o Ireland.

The coal splits most readily along the planes of lamination, or "with the grain," as it would be commonly expressed. The surfaces thus exposed on the tops and bottoms of the lumps are generally dull and earthy, and readily soil the fingers. At right angles to these surfaces others may be observed which are generally bright, and if the coal be freshly broken, these surfaces soil the fingers much less than those on the top and bottom of the lump. The bright surfaces which cut vertically across the lamination of the coal are generally at right angles to each other, so as to make a number of square corners, and one set of them is usually more persistent than the other, making large smooth sides to the lump, while the other sides are more jagged. The first large smooth vertical surfaces are known by the name of "the face," "the slyne," or "the cleet" of the coal in different districts—the more interrupted set being spoken of sometimes as "the end" of the coal. The "face" of the coal is the most necessary thing to attend to in laying out the working galleries or gate-roads of a coal-mine, since it retains its parallelism over very large* areas, and the main galleries must necessarily be driven along it, while the cross galleries run along the "end" of the coal. Sometimes the "face" of the coal suddenly changes its direction, and I was assured by Mr. Peace jun. of Wigan, when examining his coal-mines, that this is especially the case on opposite sides of a large fault. In some cases this occurs even in the same colliery, as at the Haigh Colliery, near Wigan, in which the face of the coal at one part runs in a direction 20° or 30° different from that in another, involving a similar obliquity in the "gate-roads."†

Professor Phillips‡ says, that in the whole of the North of England coalfields the strike of the cleat, or face, is about north-west and south-east, whatever may be the strike or dip of the beds. Mr. Warrington Smyth§ says that in some parts of the North of England the two planes of division are oblique to each other, so as to make "rhombohedral" coal. Indurated black shales, especially when slightly calcareous, sometimes separate into small regular rhombohedral slabs, not more than an inch in diameter.

I believe this to be a true "joint" structure, carried out more com-

* In inquiring of a collier in the Nottinghamshire coalfield, in the year 1838, as to the direction of "the slyne" (as the face is there called), I was informed that it "faced two o'clock sun, like as it does all over the world, as ever I heered on," by which I understood that the sun would shine directly upon it at two o'clock in the afternoon in an open work, or that the planes ran about W.N.W. and E.S.E., and were persistent in their direction, in all my informant's district at all events.

† In the Wigan district the "gate-roads" are called "brows," and are spoken of as "up-brows" and "down-brows," according as they rise or decline from the "levels." The shorter passages which connect these "brows" are called "drifts."

‡ In his *Report on Cleavage*, presented to the British Association for 1856 (p. 395).

§ In his excellent little work on *Coal and Coal-Mining*.

pletely and minutely through the mass of the coal than through most other rocks, as we might expect in one of such a fine grain, light specific gravity, and homogeneous substance, as coal, and one that has been subject to so much contraction as it passed from a mere mass of vegetable matter into the consistence of a rock.

Dip-Joints and Strike-Joints.—When a joint runs in the direction in which the strata are inclined (or with their *dip*), it is called a *dip-joint;* when it runs at a right angle to the dip (or along the *strike*), it is known as a *strike-joint.*

Art of Quarrying.—The shape of a quarry will depend altogether on the direction of the master joints which traverse the stone. One set of these joints will form what is called the "face" or "back" of the quarry, or the boundary wall towards which the men are at any time working, while the other set of joints at right angles to these are those along which they work, and these are called the "ends," or sometimes the "cutters" of the stone. The terms seem often to be used rather vaguely by quarrymen, just as they use the term "bed" or "floor" to signify sometimes a true bed surface, sometimes merely a surface formed by a horizontal joint. Whatever may be the terms used, however, it is clear that the whole art of quarrying consists in taking advantage of the natural division of rock by joints and planes of lamination and stratification where the latter exist.

Prismatic Joints.

The joints hitherto spoken of produce blocks which are more or less cuboidal in shape. In some rocks, however, the jointed structure has a tendency to produce long polygonal prisms, often resembling dry starch, in their irregular and wrinkled sides. This prismatic jointing is most frequently exhibited in igneous rocks, such as the doleritic lavas and the traps, being especially characteristic of basalt, but occurring sometimes almost as perfectly in some greenstones and felstones. There is even sometimes an approximation to it in granite, for the possibility of procuring long monoliths is the result of a more or less prismatic arrangement in the joints.*

It is also observable in sandstones and clays that have been acted on by great heat, either naturally or artificially, and is occasionally, though rarely, observable in purely aqueous rocks, especially those of a chemical origin.

I observed, in the year 1855, a good example of prismatic jointing in the gypsum quarries of Chaumont, near Montmartre, Paris. Two beds, each six or eight

* The columnar structure is sometimes perceptible in the granite of Cornwall. See *Trans. Royal Geol. Soc.*—Cornwall, vol. iii. p. 290.

feet thick, of crystalline granular gypsum occur there, interstratified with the fresh-water marls and limestones, and each of these was affected by a prismatic jointing, while in the soft clays between them few or no joints were observable. The prisms were pretty regularly triangular and hexagonal, as in Fig. 38, and seemed to have been produced by the intersection of three sets of vertical equidistant planes crossing each other at angles of 60°. If three such sets of planes intersect each other in the same points, triangular figures only could be produced; but if the planes be so arranged as that no more than two should ever intersect at the same point, and that each point of intersection be equidistant from the planes of the third set, the result will be the production of a series of regular hexagons and triangles, as shown in the figure.

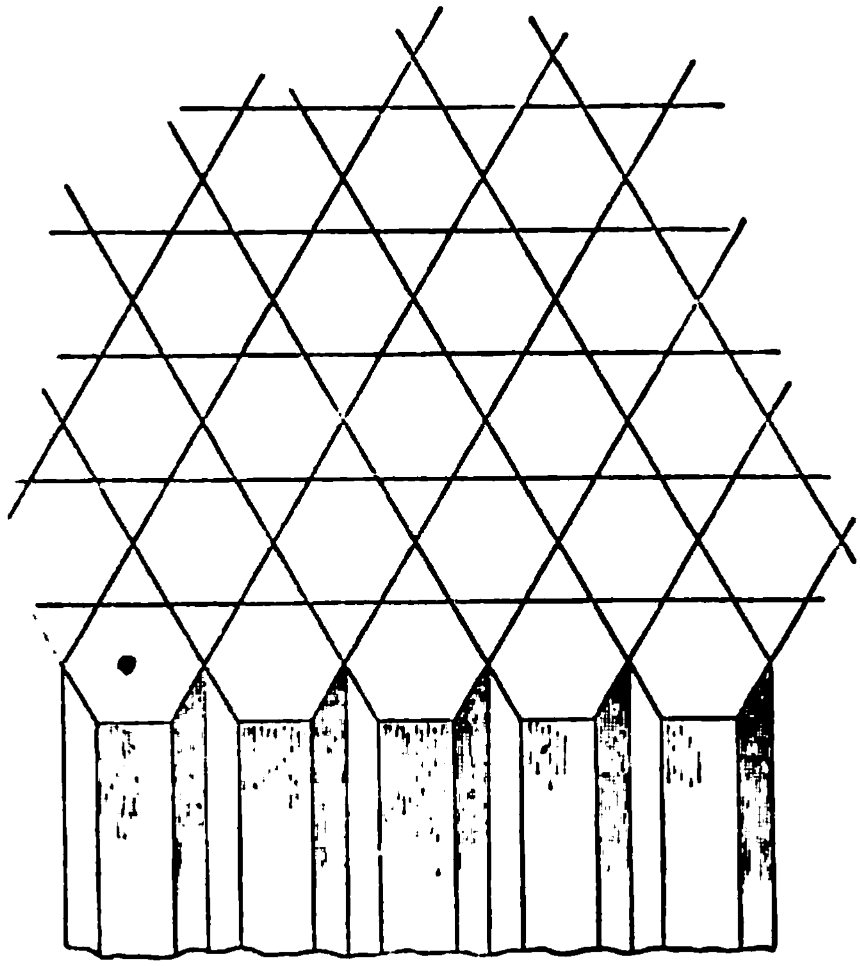

Fig. 38.
Joints in beds of granular gypsum (Chaumont, near Paris).

Columnar basalt is a familiar example of this prismatic jointing. Basalt occurs sometimes in thick horizontal beds, the columns in that case being vertical, sometimes in highly inclined or vertical dykes, in which case the columns are nearly or quite horizontal. In each case the columns are at right angles to the surfaces of the mass, where the consolidation would necessarily commence, and appear to have struck thence into the interior. It is often observable that in dykes the columns are separated in the middle, and do not fit each other, as if each set had originated at the side of the dyke, and struck towards the centre, where they met, but did not coalesce, as in Fig. 39. In some cases the columns are more or less unbroken for many feet, a few cross joints only occurring at irregular intervals. This is especially the case in prismatic felstones.

Articulated Columns in Basalt.—In other cases, however, especially in the most perfectly columnar basalts, the columns are articulated, each prism being separated into vertebræ, with a cup and ball socket occasionally developed on their upper or lower surfaces. The origin of this articulated cup and ball structure was explained by the observations of Mr. Gregory Watt. If a mass of basalt be melted in a furnace, and allowed to cool again, the following results may be observed. If a small part be allowed to cool quickly, a kind of slag-like glass is formed, not differing in appearance from obsidian. If it cool in larger mass and more slowly, it returns to a stony state. During this process small globules make

their appearance, which, very small at first, increase by the successive formation of external concentric coats, like those of an onion. As external coats are successively formed, the internal ones seem to coalesce and disappear, so that ultimately a number of large solid balls are formed, each enveloped in several concentric coats. As these balls increase in size their external coats at length touch, and then mutually compress each other. Now, in a layer of equal-sized balls, each ball is touched by exactly six others (see Fig. 40), and if these be then squeezed together by an equal force acting in every direction, every ball will be squeezed into a regular hexagon. But the same result will follow from an equal expansive force acting from the centre of each ball, or from the tendency to indefinite enlargement in their concentric coats. Each spheroidal mass, therefore, will be converted into a short hexagonal pillar. But if there are many piles of balls one above another, each ball resting directly and centrically on the one below it, we should have a long column of these hexagonal joints, and the top and bottom of each joint either flat, concave, or convex, according to variations in the amount and direction of the pressure at the ends of the columns.

Fig. 39.
Dyke of columnar basalt, the columns not continuous across.

This appearance of a globular concretionary structure is doubtless merely a case of the tendency to form nodules, possessed by many rocks, to which reference will be made in a subsequent chapter, and does not in itself give rise to the columnar structure observed in basalt and other rocks. The columnar form is merely an instance of prismatic jointing, and exists in many rocks which exhibit no tendency to the production of regular articulations in the columns, nor any cup and ball structure in the surfaces of those articulations, nor any appearance of nodular balls with concentric coats. It is the same tendency to form columns, while the substance consolidates, which is exhibited by starch. In starch this columnar structure seems to have a tendency to radiate from certain

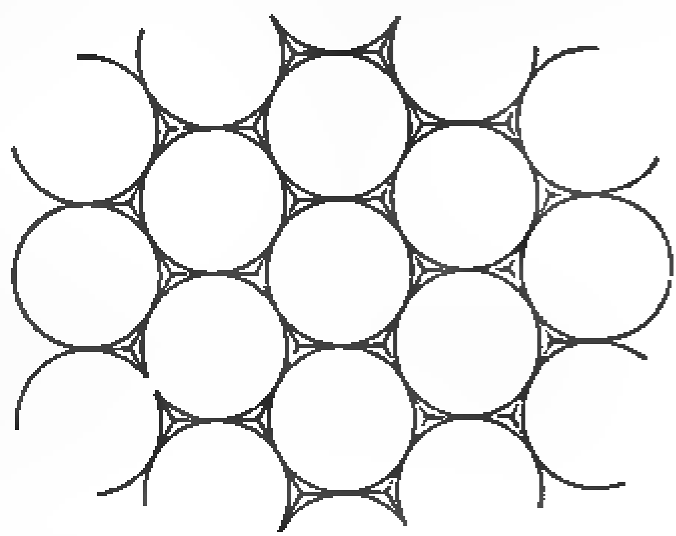

Fig. 40.

centres, and the same tendency may often be seen in basalt and other igneous rocks.*

The pillars of basalt are usually from 6 to 18 inches in diameter, and vary in length from an inch or two to 100 or 150, or sometimes (according to Macculloch), to 400 feet. Columnar greenstone is commonly on a larger scale, the pillars being sometimes 5 or 6 or even 8 feet in diameter, and the columnar form of the rock is often only to be perceived at a distance. Almost all greenstone exhibits the tendency to decompose into rounded spheroidal blocks, on which we have just seen the columnar structure partly to depend. Felstone is sometimes also beautifully columnar, of which an admirable example may be seen in a small pass to the southward of Lough Gitane, near Killarney,† where the columns are 200 feet long. Great masses of columnar felstone are also to be seen about Snowdon and other places in North Wales.‡ The syenite of Ailsa Craig, in the Firth of Clyde, shows large rude columns, 9 feet across, and upwards of 400 feet high.§

Slickensides.—In many cases, especially among igneous rocks, the surfaces of joints, as well as the opposite walls of "faults," are coated over with a film of mineral matter (carbonate of lime, epidote, hæmatite, etc.) exhibiting very distinct parallel striæ. These striated surfaces are called *slickensides*. They occur more abundantly in districts which have been much affected by movements of disturbance.

Cause of Joint Structure.—In seeking for a cause for the production of joints in rocks, the most obvious one that occurs to us is the contraction of the rock during its consolidation. Mud or clay cracks in drying; molten rock shrinks and cracks in cooling. One of the chief difficulties experienced in large castings either of molten metal or in plaster casts is to guard against the formation of cracks, and this difficulty increases with the bulk of the material. It has been several times attempted to turn to account the "slags" derived from iron furnaces by allowing them to run into moulds. An attempt was once made in South Staffordshire to run them into moulds of the size of large building-stones, and I have seen a large wall made of these molten blocks. The attempt, however, was abandoned, because after a short time the blocks crumbled into small cuboidal fragments, in consequence of the numerous minute concealed "joints" that traversed them.

In examining the newly formed beds of stone in the small islands upon coral reefs, I always found them divided by joints like other rocks. The consolidation of this stone was obviously due to the action of rain-water dissolving part of the carbonate of lime and redepositing it as a cement, so as to bind together the previously incoherent coral sand; for the stone generally rested on, and was surrounded by, coral sand still

* For illustrations of the columnar structure see the Chapter on the Trap-Rocks viewed as Rock-Masses.

† See papers by Messrs. Du Noyer and Foot, *Jour. Geol. Soc. Dublin*, 1856; and Explanation of Sheet 184 of the Maps of Geol. Surv. Ireland.

‡ See Professor Ramsay's Memoir on North Wales, *Mem. Geol. Surv.*, vol. iii. p. 112.

§ See Macculloch's *Western Isles*, vol. ii. p. 493. *System of Geology*, ii. p. 137.

incoherent. Among the coral islands on the north-east coast of Australia I often observed several beds of stone resting on each other, each more than a foot thick, inclined at an angle of 8° or 10°; that is to say, at the same angle as the slope of the beach or bank of sand on which they rested. They had to all appearance been consolidated in this position. The joints which traversed them, although often uneven and jagged, ran in straight parallel lines over spaces sometimes of 200 yards, or as far as they could be seen, their planes being generally vertical, one set of joints running along the greatest linear extension of the mass (strike-joints), and the other set directly across the former, and in the same direction as the inclination of the mass (dip-joints). It seems difficult even to imagine any other origin for the joints in these cases than the action of contraction upon the consolidation of that portion of the mass which was converted from loose sand into solid stone.

It does not by any means follow that all the joints in any mass of rock should be formed at once. The consolidation of the mass may take place slowly and gradually, and successive sets of joints be produced in it at different times during that process. A rock moreover may be at some subsequent period more consolidated, and a fresh set of joints may be produced in it. Neither does it follow that contraction on consolidation is the only agent that can produce joints, since they may be formed in a mass of rock that is in a state of tension from a mechanically expanding force.

The short joints confined to individual beds of stratified rocks may have been those first formed on the original consolidation of the one bed before the other was deposited on it, those joints being then perhaps quite imperceptible divisional planes, with no interspace between the blocks. Whole sets of beds may have subsequently been subject to one, two, or more actions, which may have produced larger joints traversing the whole mass. Still more extensive joints may have been formed subsequently by the mechanical agency of forces acting on the crust of the globe. In those parts where the rocks have been subjected to the expanding power of heat, and the consequent contraction on its withdrawal, many more numerous joints may have split the rocks into smaller and smaller blocks, as is sometimes to be seen in the aqueous rocks in contact with trap-dykes or other igneous masses. It would be no easy task now to assign to each particular cause the numerous joints which may be observed in all highly indurated and disturbed rocks.*

Apparent Absence of Joints at great depths.—It is often said by vein-miners who have worked at great depths, that the jointed structure of rocks fades away and disappears in the deeper parts of the mines. This, however, is probably a case of the rule "de non apparentibus et

* See papers on jointing by Professor Sedgwick; by Professor Harkness, *Journal Geol. Soc. Lond.*, vol. xv. p. 37; and by Dr. Haughton, *Phil. Trans.*, vol. cxlviii. part 2.

non existentibus eadem est ratio." All the joints near the surface are more or less acted on by the weather. The deeper seated rocks may be just as much traversed by joints, but they are merely mathematical planes of division, the faces of the blocks adhering as closely as if they did not exist till the weather makes them apparent, or some force tears the blocks asunder.

Surface Exhibition of Joints.—In some places the jointed structure of rocks is sufficiently striking to attract the notice even of ungeological observers. In Van Diemen's Land, at a place called Eagle Hawk Neck, the rock, of which a large surface is exposed at low water, is so regularly cut by joints into equal cubes, of about one foot in the side, that it has become a local celebrity, under the name of the "tessellated pavement." The study of joints and the other divisional planes of rocks, and the different forms assumed by them in consequence, both when freshly exposed and when modified by "weathering," is as necessary for the landscape-painter who wishes to reproduce nature, as is the study of anatomy to the figure-painter. Mr. Ruskin has handled this subject in his usual masterly style.*

Natural Erosion of Rocks in consequence of Joints.—The jointed structure of rocks facilitates their removal by natural causes, as it does their artificial extraction by the quarryman. In cliffs a slight undermining action, if it happen to cut back to a strong vertical or highly inclined joint, running parallel to the shore, causes the ruin of vast masses of rock. Not unfrequently, too, a long strip of rock lying between two well-marked joints, closer than usual together, and running into the land at right angles to the coast, has been entirely cut out, giving access to the eroding action of the breakers deep in among the rocks on each side of it.

A rock, even though very hard, such as quartz-rock or crystalline limestone, will be much more easily carried away by breakers or other moving water, if it be cut up by many joints into blocks of a convenient size and shape, than much more yielding rock, if it be massive, and either unjointed, or the joints be few and far between, and the sides of the blocks very close together, so as not to admit easily of the access of either air or water.†

* See *Modern Painters*, vol. iv., etc.

† See the description of sea action in the section on Geological Agencies.

CHAPTER VIII.

INCLINATION OF BEDS.

The Dip and Strike of Beds.—The inclination of beds downwards into the earth is technically called their "dip." It is measured by the angle between the plane of the beds and the plane of the horizon. In the map, Fig. 41, the beds dip S.S.E. at an angle increasing from 35° to 50°. When we speak of the opposite of "dip," we use the term "rise." For instance, the beds in the figure *dip* to the south, and *rise* to the north. The place where each bed rises out to the surface of the ground is called its "outcrop" or "basset." We say that such and such beds "crop out" to the surface, and we speak of the "basset" edges of the beds. Miners use these and other terms, such as "coming out to the day," "rising up to the grass," when speaking of the "outcrop" of any bed or beds. The line at right angles to the dip—that is, the line of outcrop of a bed along a level surface—is called its "strike," a term introduced from the German by Professor Sedgwick. It is described by its line of compass bearing, either true or magnetic.* Coal-miners commonly speak of this as the "level bearing" of a bed, seeing that if you draw a line or drive a gallery along a bed exactly at right angles to its line of dip or inclination, it must of necessity be on a true level or have no inclination either way. It must be recollected that the strike of a bed will coincide with its outcrop only when the surface of the ground is horizontal. If the surface be highly inclined, the outcrop of the bed will depart from the true strike in proportion to the inclination of the surface, until it coincide with the dip when the surface becomes perpendicular.

If, then, a bed "dips" due north or due south, its "strike" will be due east and west. If we know the direction of the "dip" of a bed, accordingly, we also know the exact bearing of its "strike;" but if we only know the strike, we do not necessarily learn either the direction or amount of its "dip," because it may incline to either side of the line of strike, and to any amount from the horizontal plane. In making observations, then, in field geology, it is most important to observe

* Geologists generally use true compass bearings, a practice that ought to be adopted universally in all land operations.

accurately the direction of the dip of all stratified rocks. It is also important to know its amount ; but this need not be observed with

Fig. 41. Geological Map.

such minute accuracy, except in special cases, since it is apt to vary continually to the amount of 3° or 4°.

Geological Map and Section.—In order to make the explanation more clear, let Figs. 41 and 42 be a rough map, and a section across it, of a supposed piece of ground near the shore, and let them both be drawn on a scale of about 100 yards (or 300 feet) to the inch. In the map, Fig. 41, let A A be a rocky beach, exposed at low water; B B a line of cliff about 100 feet in height; and C C the surface of a country above the cliff, with the rock exposed in several places, either on the summits of eminences or the bottoms of quarries. The arrows will point out the direction of the dip, the figures showing its amount. This amount increases from 35° on the north to 50° on the south, and we may assume this increase to be quite gradual, or that the beds are parts of curves, and not of perfectly straight planes. Then let D D be a line of section, or supposed cutting, at right angles to the strike of the beds, and let this section (Fig. 42) be drawn so as to give the true outline of the ground across which it passes, and represent the beds in the true position they would be seen to occupy were such a cutting or cliff really formed. Being drawn at right angles to the strike, it runs of course along the line of the direction of the dip, and its bearing, as here drawn, is about 28° west of north and east of south. The latter, then, is the *direction* of the dip. The bearing of the strike will consequently be 28° north of east if we look in one direction, 28° south of west if we look in the other. In such a locality as this, if we marked out the boundaries of the beds correctly on our map, we should feel sure of the correctness not only of the map but of the section, and we should know the position of the beds not only above the level of the sea but for a considerable distance below it. If, for instance, at the point *d* in the map, we wished to determine the vertical depth of the bed *b*, we should see at once, by constructing the section, that the depth of *b* under *d* would be, according to the scale, rather more than 425 feet.

Fig. 42.
Vertical section along the line D D in the map, Fig. 41.

It would be easy for us also to ascertain the total actual thickness of the whole

set of beds shown on the map, either by actual measurement of each bed along the shore, or by constructing a section founded on the observation of their angle of dip and the width of their outcrop. The actual thickness of the beds cut by the sea-level line in the section Fig. 42, for instance, would be a little over 850 feet. That is to say, those beds, if they were horizontal, would be 850 feet from top to bottom; if they were vertical, it would be 850 feet directly across them; while in their present inclined position a horizontal line across their outcrop measures 1200 feet.*

If we proceeded to trace those beds into the country *along their strike*, however much the direction of the strike or the *angle* of the *dip* might vary, or however they might be concealed by grass, soil, or superficial covering, we should always have to recollect that there was a thickness of 850 feet of beds to be found or allowed for somewhere; and if we came to a quarry or a cutting where the bed *x*, for instance, was shown, and we were able certainly to identify it, we should expect there to find all the other beds above and below it that we had found above and below it where they were clearly exhibited. We should feel sure we were right in this, if in the expected spots, at the requisite distance on either side of it, we found one or more of the beds *a*, *b*, or *c*, shown in other quarries, or cuttings, or cliffs in the neighbourhood.† It is in this way, by getting a knowledge of the true section of a series or group of beds where they are well exhibited, and following them across a country, picking out one of them here, and another of them there, in ditches, brooks, river banks, cliffs or ravines, wells, mines, road or railway cuttings, and quarries, that geological maps are constructed, showing the boundaries of the several groups of rock, their range or strike across a country, and the area of surface occupied by the outcrops of their various members.

Contortions.—Where the dip and strike of the rocks are very steady, or where they run in nearly straight lines across a country, and their edges are not too much concealed by superficial covering, the task just mentioned is one of no great difficulty. In many instances, however, neither the dip nor the strike of a set of beds remains constant over any considerable spaces. The beds are bent and twisted about, so that, instead of running in straight lines, the basset edges, or outcrops of any set of beds, follow crooked and curved lines, often doubling back and running altogether out of their former course. Moreover, after dipping down in a certain direction for some distance, such beds are frequently curved up again, and rise to the surface at some other locality, forming basins or troughs; or, again, after cropping out to the surface, the beds underneath them are bent over in a ridge-like form, so that the first beds come in and take the ground again, dipping in an opposite direction. These are often called "saddles." Such bendings of the beds occur on every possible scale, from mere little local crumplings on the side of a bank, to curves of which the radii are miles, and the nuclei

* In the Appendix will be found a table which will give for different angles of dip either the depth of any particular bed at any given distance from its outcrop, or the thickness of a group of beds when the width of their outcrop is measured at right angles to their strike.

† In diagram, Fig. 41, the supposed quarries or exposures of rock in the interior of the country are thickly grouped together; but if the reader will imagine them separated by much wider intervals, and scattered over a far larger space, he will have a truer notion of what usually occurs in nature.

are mountain chains. When on the small scale they are commonly called "contortions," as in Fig. 43.

Fig. 43.
Sketch of a cliff on the coast of Cork, near the old Head of Kinsale, by Mr. G. V. Du Noyer.

Beds of the hardest stone, such as compact or crystalline limestone, and hard siliceous gritstone, are in some cases bent into curves of the most wonderful regularity, so as to look like artificial masonry, or a series of arches and troughs built for some inexplicable purpose. More usually, however, there is a good deal of irregularity in the curves, and this is especially the case when the beds acted on consist of alternations of different texture and composition.

Fig. 44.
Sketch of contortions in carboniferous limestone and shales, Loughshinny, County Dublin.

The sketch, Fig. 44, represents part of a series of contortions in the Carboniferous limestone of the County Dublin, as they may be seen on

the shore of Loughshinny, between Rush and Skerries. In this locality they may be studied not only in section in the cliffs, but in plan on the shore at low water, and some of them may be observed partly in section and partly in plan, which makes the locality an exceedingly interesting one.

The " saddles " and " troughs " often form long ovals, and look like nests of boats, one inside the other, some upright, but broken and cut down atop, others bottom upwards, and broken into from the outside, so as to show parts of those within. These forms succeed and replace each other in all directions, and where the one passes into the other, the crumpling has been sometimes so great, and the squeezing so severe, that it is impossible to trace any bed, or even any two or three beds through the contortion.

It will be seen that in some parts of the sketch (Fig. 43) the dark shale-beds are wider than at others, the soft shales having been squeezed out from between the limestones at one place, so as to form "pockets" at another. This sometimes happens, on a still larger scale, with the softer and more squeezable parts of violently contorted beds. In the collieries near Kanturk, County Cork, the culm and anthracite beds there, which were originally perhaps 2 or 3 feet thick, expand in some places to a width of 20 or 30 feet, while at others they dwindle down to a single inch. The same thing seems to occur with the seam of anthracite in the Lower Silurian beds near Upper Church, County Tipperary, and at Kilnaleck, in the County of Cavan.*

Very curious and almost inexplicable contortions may be seen occasionally, but we must recollect that the conditions under which they were produced were such as it is not often possible for us to imitate, nor easy even to imagine. When the rocks were thus contorted, they were buried under vast thicknesses, often many thousands of feet, of other rock ; the rocks above and below them were also of unequal densities, and offering unequal resistances to force ; the forces of disturbance, therefore, even if uniform in their origin, would become complicated in direction, and unequal in intensity, by reason of these inequalities in the structure and position of the rocks, and inequalities in the pressure of the superincumbent masses.

Repetitions of disturbing Action.—Another source of confusion is the repetition of a disturbing action upon rocks already disturbed, the subsequent forces acting perhaps in directions different from the early ones. In Ireland it can be shown that the Cambrian rocks were greatly disturbed and contorted before the deposition of the Lower Silurian, that the Lower Silurian formation had in like manner suffered before the deposition of the Carboniferous, and that the Carboniferous had itself

* See Explanation of Sheets 145, 163, and 175, Geol. Surv. Ireland; description by Messrs. G. H. Kinahan and A. B. Wynne.

been greatly disturbed and often highly contorted. It is reasonable therefore to expect, what is found to be the fact, that the beds of the Cambrian rocks are in some places twisted into a confusion of curves and knots, which it is now a quite hopeless task to endeavour to unravel.

Anticlinal and Synclinal Curves.*—When the curves of the rocks are of greater extent, we cease to speak of them as mere "contortions." If the curves have long-extended axes—that is to say, if the beds are bent up into ridges, or down into troughs, which continue for considerable lengths, in proportion to their widths—we speak of them as "anticlinal" and "synclinal" curves. If, on the contrary, no diameter of the curved area be much longer than another, we call them either dome-shaped elevations, or basin-shaped depressions, as the case may be.

In the section (Fig. 45), A is an anticlinal, and B is a synclinal curve, the beds numbered 6, 7, 8, being repeated on each side of both.

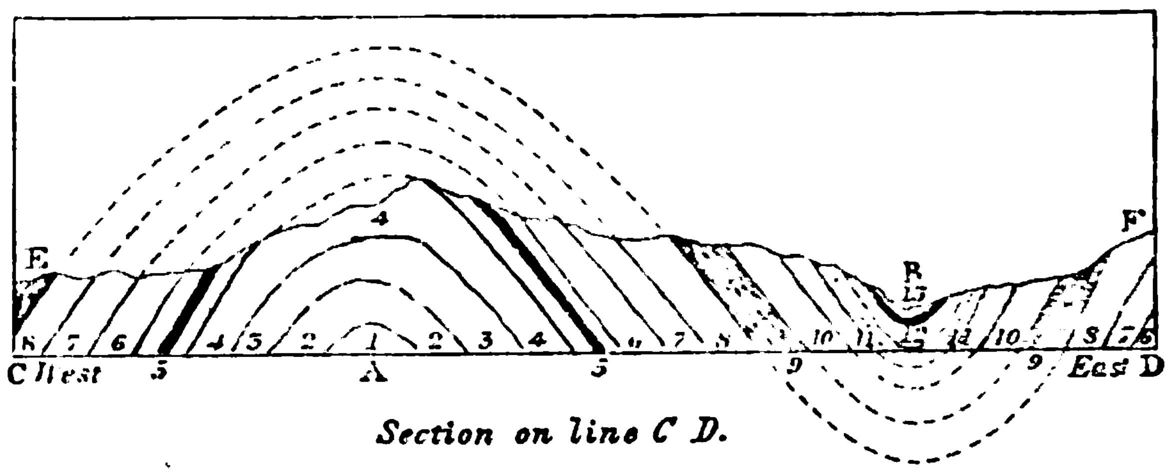

Fig. 45.

At A, the lower beds, 1, 2, 3, 4, 5, are seen rising out from underneath them in the form of an arch. At B, the upper beds, 9 to 13, repose upon them in the form of a trough. It matters not whether we suppose the spaces, 1, 2, 3, etc., to represent single beds, and the hill at A a slight elevation, or whether they be taken as groups of beds, and A be supposed to be a mountain chain. The imaginary line which runs from the eye of the spectator through A and B, and about which the beds may be supposed to be bent, is called the "axis" of the curve in each case. This axis may be either horizontal or inclined; if horizontal, the section across it will cut the same beds wherever it be taken, the variations in its outline being only those in the outline of the ground. If, however, the axis be inclined, different sections will cut different beds, even should the outline of the ground remain the same.

* The English words "saddle and trough" might be used for these terms, were it not that these words are often used by miners with other meanings. Near Llanelly, in South Wales, for instance, I found that they spoke of a synclinal curve not as a "trough," but as a "saddle," meaning, I suppose, a saddle upside down. Moreover, "saddle and trough" are often used as denoting external forms of ground with which the internal structure is often in direct opposition, a saddle-formed hill often rising over a geological trough, or a trough-like valley running along the axis of an anticlinal or saddle-like curve in the beds.

This is shown in Fig. 46, which is a supposed plan of the ground of which Fig. 45 is a section. In this the axes, A A' and B B', are sup-

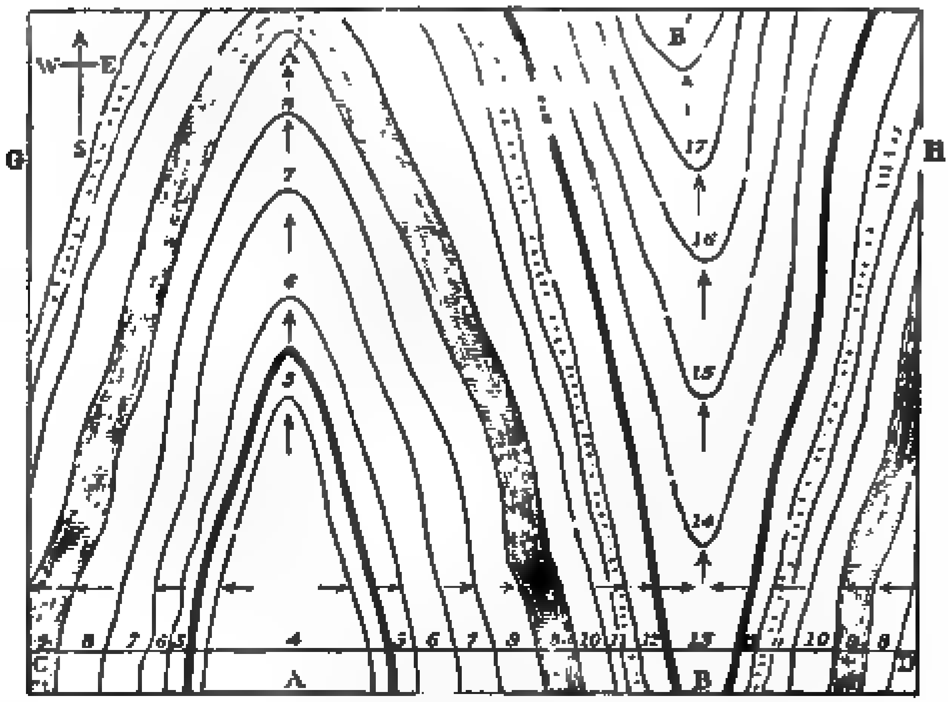

Fig. 46.
Plan of undulating beds.

posed to incline downwards to the north, or from the line of section C D, to the other end of the map, as shown by the arrows, and it is obvious that the bed 4, which forms the apex of the ridge in the section, will slope downwards along the inclined axis, and if the ridge of the hill be kept up to the same height, the beds 5, 6, 7, 8 will necessarily arch over it. In the same way, if the synclinal axis B B' slope in the same direction, there must either be a corresponding slope and hollow in the surface of the ground, or fresh beds, 14, 15, 16, etc., must come in, resting in the hollow of 13. So that, if we make

G

Fig. 47.
Section along a line between G and H.

another section, as in Fig. 47, along a line between G H for instance

in Fig. 47, the ridge of the anticlinal A A[1] will be formed by the bed 7 instead of 4, all the beds below 7 having successively sunk beneath the surface, and the bed 16 will form the hollow of the synclinal B B[1], the bed 13 being now at a considerable depth below it, and cropping out at some distance on either side.*

Large anticlinal and synclinal curves have often minor undulations on their flanks, as suggested in Fig. 48, where the letters *a* and *b* show

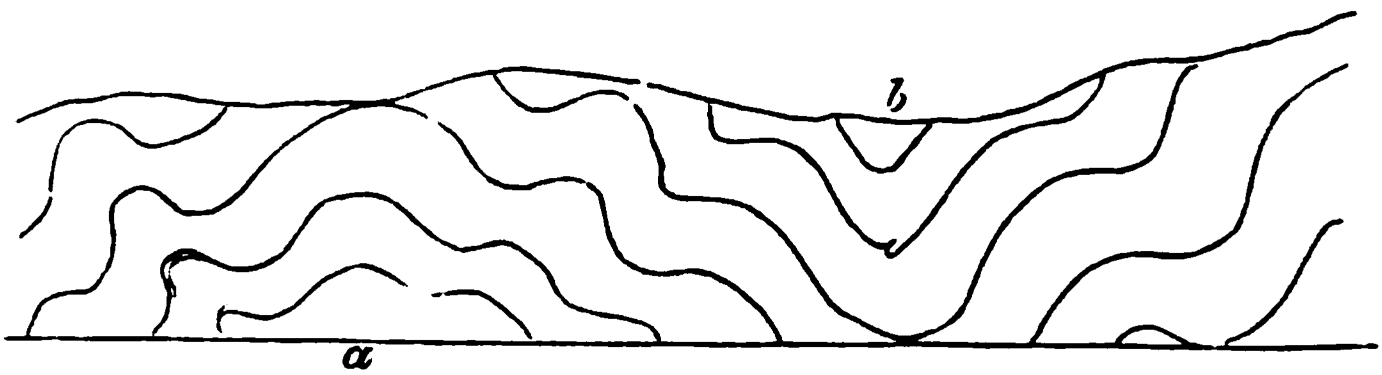

Fig. 48.
Sketch section, to show major and minor folds in rocks.

the main anticlinal and synclinal, with smaller ones on each side. These minor undulations may be likened to ripples or lesser waves riding on the back of the larger swell of the ocean. They are especially remarkable in some of the large anticlinals in the south-west of Ireland.

It will be readily understood that such complication of forms as these necessitate great labour in making an accurate geological map of a country, more especially where the ground is itself lofty and broken, and often difficult to traverse, while the subterranean complication is often only partially revealed by occasional exposures here and there at the surface.

The axes, or imaginary central lines of anticlinal and synclinal curves, are sometimes long and steady, and the curves themselves, of course, equally so ; sometimes the axes are short and interrupted when the anticlinals and synclinals shrink into short oval ridges and troughs, like those mentioned at p. 190, and these again pass into strictly dome-shaped elevations and basin-shaped depressions, when the axes become mere points or centres, from or towards which the beds have

* In the cant phrases that have got into use in the Geological Survey, the beds that thus sink under the others along the crest of an anticlinal are said to "nose in" under them, and the beds that thus terminate across the trough of a synclinal are said to "nose out" over them. Attention to the inclination of the axes of these curves is not only necessary in geological surveying, but is of the greatest practical importance in bed-mining. I was myself cognisant a few years ago of an abortive sinking for coal in the South Welsh coalfield, where something like £30,000 was wasted, mainly from want of attention to this circumstance, the coal that was being sought having cropped out across the axis of the synclinal a mile or more before reaching the spot where the shaft was being sunk for it.

what is called a *quâ-quâ-versal* dip or inclination on all sides. Sometimes also the axis of a curve undulates along its extension, so that after higher beds have been brought in over it, the lower ones may begin to make their appearance again in the same general strike, or *vice versa*, and sometimes even the curves themselves are irregular, so that an anticlinal presses into a synclinal along the same line of strike, and *vice versa*.

The axis of an anticlinal or synclinal curve necessarily runs in the direction of the general strike of the beds; but instances are not uncommon of minor curves, the axes of which run obliquely to the general strike, or even in the direction of the dip of a mass of beds. It is, however, obvious that these can only be of subordinate importance, or they would themselves produce a general new dip and new strike in the beds they traverse.

Uniclinal Curves.—This term, first used, so far as I am aware, by Mr. Darwin, in his *Geology of South America*, may be useful sometimes to designate a single fold in rocks, without any answering counterfold in any direction.

In the Isle of Wight, for instance, the beds are horizontal at the southern end of the island, suddenly dip in the middle of it at a high angle to the north, and then rather quickly recover their horizontality at the northern end of the island. This uniclinal curve causes the beds which cap the hills in the south to be deep below those forming the low ground in the north of the island.

Some magnificent examples of uniclinal curves may be seen along the cliffs near Loop Head, County Clare. The beds there are hard grits and indurated slaty shales belonging to the Coal-measures. In many places they are horizontal, or nearly so, while in others they are variously curved, the anticlinals sometimes eroded by the sea below, so as to form natural arches and bridges, one example of which is well known as the Bridges of Ross. In two or three instances, however, horizontal beds are suddenly bent for a short space by uniclinal curves into the vertical position, and then immediately bent back again into the horizontal. The axes of these curves strike nearly with the coast, so that great areas of the surface of a bed are sometimes shown in the cliffs. One of these is one or two hundred yards long and two hundred feet in height, and Mr. Henry Keane, on whose property it is, has had one of the projecting crags near it walled round, so that it may be viewed in safety. As the smooth nearly vertical surface of the bed undulates slightly, it might be taken for the side of some mighty ship rising out of the boiling surf below.

Inversion of Beds.—These flexures are in some instances carried out so far, both on the large and small scale, as to produce actual inversion (see Fig. 49) of the beds, so that the lower surfaces appear in some places to be the upper ones.

This inversion may, in some cases, among highly contorted beds, be actually seen in the cliffs, as in some parts of the Alps, where the

beds may be observed bent into the form of S's or Z's, in the precipitous sides of the mountains. In other cases it requires a more widely extended observation, in order to show that the apparent order of super-

Fig. 49.
Section showing inversion.

position of any set of beds, in any particular locality, is the inverse of that order which is to be observed generally, and where the beds are undisturbed.

In parts of the Alps inversion takes place on a very large scale, so that whole districts have their beds uptilted and bent back in such a way that the lower beds rest apparently upon those which were originally deposited upon them, and the lower appears to be the higher part of the series.

An excellent case of inversion, like that suggested in the left-hand part of the figure above, may be seen in a large quarry in the carboniferous limestone at a place called "Yellow Furze," in the County Meath, a few miles south of Slane.

The inversion of beds is occasionally observed in coal-mining, as in Belgium and the south-west of Ireland, where beds of coal are sometimes found with the "coal-seat" uppermost, and the "coal-roof" undermost. In a disturbed part of the South Staffordshire coalfield, the same bed of coal was passed through three times in the same vertical shaft, first in its right position, then inverted, and then again right side uppermost. It must accordingly have been bent into the shape of the letter S or Z. We shall see presently that no mere "fault" can thus bring part of the same bed twice into a vertical shaft.

Artesian Wells.—Artificial wells known as Artesian, from their first being used in the province of Artois, are sunk in those districts where the rocks have been bent into a basin-shaped curve. If a series of beds, some of which are porous, either in consequence of their open grain, or the joints which traverse them, while others are impervious to water, be bent into the form of a basin with a qua-qua-versal dip towards a central part, and the porous beds rise into higher ground than that central part, then the rain that falls on their outcrop will partly sink down along them beneath the impervious covering, until a basin-shaped sheet of water be accumulated below, as in the shaded part of Fig. 50. This water may completely saturate the porous bed up to a certain level, as L L for instance, but will be prevented from rising to the surface by the impervious beds *m m* above it. If that impervious downward-curved bed be pierced by a bore-hole, the water will tend to rise in that hole to the level L L, and this may be in some cases above the level of the surface of the ground in the low central region, as represented in Fig. 50.

In this diagram the porous beds are indicated by the letters P P, and the impervious beds by the letters *m m*. If then the wells W W W be sunk through

the upper impervious beds, the water will rise in them, either on to the surface with a jet as in the central well, up to the surface as in the one on the right hand, or up to the water-level L L in the one on the left hand. Without some

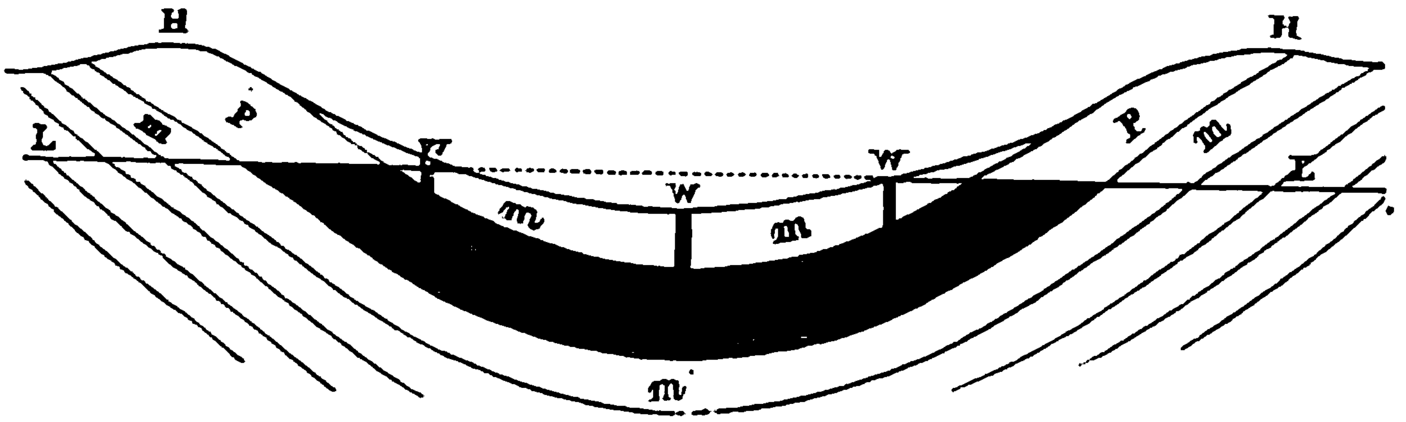

Fig. 50.
Diagrammatic section of a district in which Artesian wells are sunk.

such arrangement of the beds below ground as that now described, there is no reason why water should rise to the surface in any bore-hole, however deep it may be carried, a caution necessitated by the experience of many fruitless trials in places where there was no evidence of any such structure.

CHAPTER IX.

FAULTS OR DISLOCATIONS.

It may easily be conceived, that the force which was sufficient to raise vast masses of solid rock, of unknown but immense thickness, from beneath the bottom of the sea high into the air, in order to form the dry land, and to bend them into the folds and contortions that have been just described, was also sufficient to crack and break them through. We find, accordingly, very frequent instances of cracks running through great thicknesses of rock, which are obviously fractures caused by disturbing force. Sometimes these are mere fissures; but more frequently there is not only a severance but a displacement of the rocks that have been severed. Beds that were once continuous are now left at very different levels on opposite sides of the fissure—many feet, or many hundreds of feet, above or below the parts with which they were once continuous. When this is the case, these fractures are called "faults" or "dislocations" by geologists, for which miners in different districts use in addition the terms "slip," "slide," "heave," "dyke," "thing," "throw," "trouble," "check," and other expressions.

The Throw of a Fault.—The amount of dislocation, measured in a *vertical direction*, produced by a fault, is called its "throw," a fault being said to be an "upthrow" or a "downthrow," or an "upcast" or "downcast," according to the side from which we view it. Its amount is stated in fathoms, yards, or feet, measured perpendicularly from the surface, provided the surface be horizontal, from a given horizontal plane if it be not. If, for instance, a bed of coal, where it is cut by a fault, as at *a*, Fig. 51,

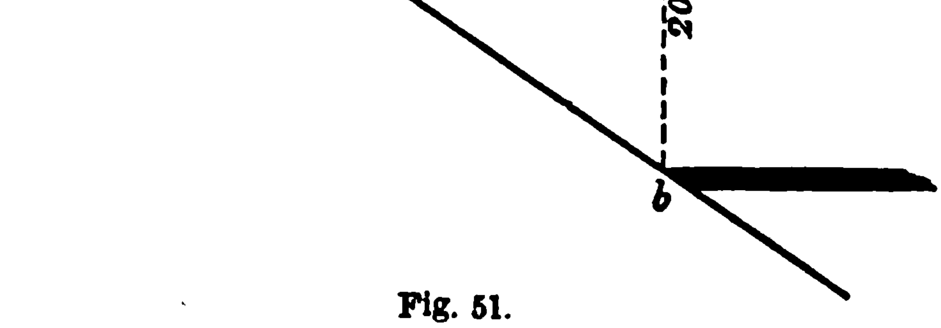

Fig. 51.
Section of a fault.

be 100 yards from the surface, or from an assumed horizontal datum line A B, and the other part of the bed immediately on the other side of the fault, as at *b*, be 200 yards below the line A B, the throw of the fault is said to be 100 yards, without regard to the distance measured laterally from A to B along the surface, or from *a* to *b* along the fault. When, however, the outcrops of inclined beds are cut by a fault, the distance between the ends of any broken bed, measured on the surface, along the line of fault, is often said to be the "heave" of the fault.

In taking accounts from miners as to the characters of faults, it is necessary to be on one's guard, and be quite sure that the sense in which they use these terms is properly understood. In some districts they would speak of the distance A B, measured along the surface of the ground, or the horizontal distance between the ends of the beds, as the "width" of the fault, looking only to the extent of "barren ground" as to that particular bed, and paying no attention to the real width of the actual fissure itself, which might be not more than a few inches, or perhaps even not one.

Statements as to the amount of the throw of faults also, especially where the beds are inclined from the horizontal, and the faults from the perpendicular, will have to be taken with great caution. Two different faults, or even two distant parts of the same fault, which have different degrees of inclination, may appear to vary greatly in throw, without producing any important variation in the position of the beds at a little distance on each side of them.

In Fig. 52, let A B and C D be such parts of faults cutting the coal L L, A B having a steep, and C D a much less angle of inclination. The throw of the fault A B will be measured by the line *a b*, that of C D by the much shorter line *c d*, and yet the position of the beds at X and Y will be the same in both cases. The part of the bed that will be lost to the miner by the steep fault A B, however, measured at the surface by the space A *o*, will be much less than that marked Z, which will be lost by the more gently inclined fault C D, and which will be measured at the surface by the space A *p*.

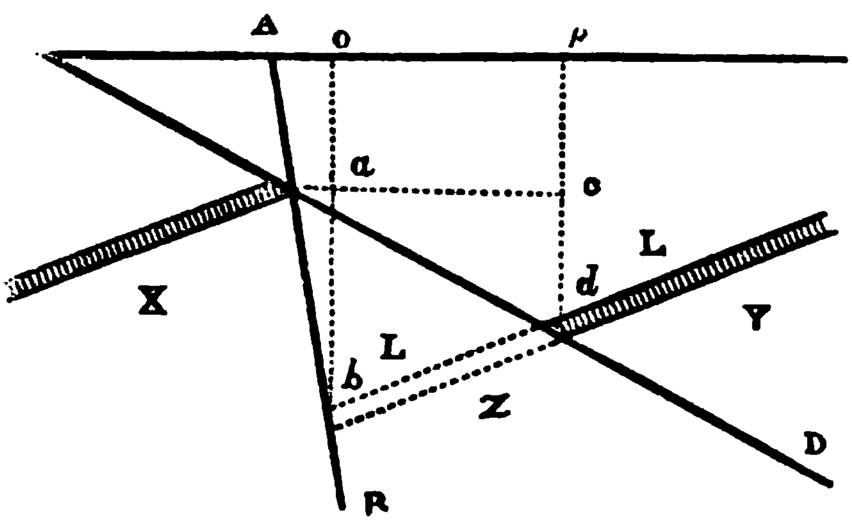

Fig. 52.

The less faults are inclined from the perpendicular, therefore, the better for the coal-miner.

Varieties of Faults.—Faults vary in *character*, chiefly according to the nature of the rocks which they traverse, whether they be hard or soft, or an alternation of both; and in *effect*, chiefly according to the position of the beds which they traverse, whether these be horizontal, inclined, or contorted, and according to the direction and number of lines of fracture, their inclination and combination.

1. Variation in Character of Faults from nature of Rocks traversed.

When faults traverse a mass of rather soft and yielding beds of rock, such as shales and thin sandstones, the fissures themselves are often mere planes of division, just as if the rock had been cut through with a knife.* In this, as in other cases, the two contiguous surfaces of the fault are very frequently found to be quite smooth and polished by the enormous friction that has taken place, producing the appearance well known to geologists under the name of "slickensides," and which has been already described in Chap. VII. In some cases, although the fracture seems quite clean and sharp, yet the beds on each side are traversed by a great number of small, irregular, and discontinuous "slickenside" surfaces, as if a jarring and tremulous grinding

Fig. 53.
Section of faulted beds without distortion.

* Dr. Tyndall, in his *Glaciers of the Alps* (p. 317), has a passage describing the first formation of a crevasse upon a glacier, which seems to me highly suggestive of what must occur in the first commencement of a fault, making allowance for some difference in the circumstances of the two cases. After pointing out that crevasses always commence as "mere narrow cracks which open very slowly afterwards," he says, "on the 31st of July 1857, Mr. Hirst and myself having completed our day's work, were standing together upon the glacier du Geant, when a loud dull sound, like that produced by a heavy blow, seemed to issue from the body of the ice underneath the spot on which we stood. This was succeeded by a series of sharp reports, which were heard sometimes above us, sometimes below us, sometimes apparently close under our feet, the intervals between the louder reports being filled by a low singing noise. We turned hither and thither as the direction of the sounds varied; for the glacier was evidently breaking beneath our feet, though we could discern no trace of rupture. For an hour the sounds continued without our being able to discover the source; this at length revealed itself by a rush of air bubbles from one of the little pools upon the surface of the glacier, which was intersected by the newly-formed crevasse. We then traced it for some distance up and down, but hardly at any place was it sufficiently wide to permit the blade of my penknife to enter it."

I have observed a somewhat similar effect in the noise resulting from the first crack, and the subsequent slow opening of the fissure when standing on the deck of a vessel that was driven stem on against an ice-floe, in order to force a way through it.

Possibly some of the noises heard during an earthquake may have a similar origin in the cracking of rocks below the surface, and faults may be afterwards slowly formed by gradual vertical displacement along these cracks deep beneath the surface of the ground, or sometimes even reaching up to it, just as the crevasses on the glacier afterwards gape slowly at the surface, and become open jagged fissures instead of mere knife-edged cuts.

motion had been produced in the mass of the beds.* Sometimes the beds end abruptly without any distortion, Fig. 53; but sometimes they seem to have been bent and distorted along the plane of the fault to a certain extent.

This bending or distortion of the beds usually takes place as suggested in Fig. 54. In this case the beds are said to "dip to the downthrow," and "rise to the upthrow," as we should expect them naturally to do. I have, however, very frequently been told by coal-miners that the contrary takes place, and that beds more usually rise to a downthrow fault rather than dip towards it. I have always received these statements with a certain amount of scepticism, but by the kindness of Lord Dudley's agent, Mr. Smith of the Priory, Dudley, I had an opportunity (referred to in the previous note) of personally examining the gate-road which he had had driven up to and across the great boundary fault at Himley, and convincing myself of the accuracy of the statement in that instance at all events. The gate-road was continued from the Thick coal some twenty yards, into the red Permian rock at a depth of about one hundred yards from the surface. Both formations were greatly shattered and broken, so much so that no trustworthy determination of the dip of the Permian beds could be made. The coal-measures were not only shattered but squeezed, so that the Thick coal lost much of its usual thickness on approaching the fault, and when it came within ten or twelve yards of it, it was bent up perpendicularly, and the beds below it rose into the walls of the gate-road, and were cut off above by the red rock lying obliquely across them at an irregular line, the inclination of which to the horizon did not exceed 37°, somewhat as in the following figure, which is condensed from a rough sketch and measurement I made on the spot.

FIG. 54.

Section of beds distorted by fault.

It is only by a lucky accident that a geologist can ever have the opportunity of personally examining such a case, as the continuance of the mining operations

* These "slickenside" or polished and striated surfaces are not confined to those near faults, since, as already mentioned, they often coat the surfaces of joints, with a thin striated deposit frequently of silica. These are attributed by Mr. Close, who has paid much attention to them, to crystallisation of the substance in parallel fibres (see paper "On some striated surfaces in the Granite near Dublin," by Revd. Maxwell Close: *Journal Geol. Soc. Dub.* vol. x.) In many cases, however, they are merely striated and polished planes of division, traversing the rock, as I had an opportunity of observing in March 1867 in the Thick coal in Staffordshire. In the Himley pits, on approaching the boundary fault, the coal on the sides and in the roof of the gate-roads had every cubic yard of its mass traversed by "slickenside" surfaces running in all directions, their number diminishing as we receded from the boundary fault, till at a distance of 50 or 100 yards from it they were rarely observable.

shortly makes the spot inaccessible, and it cannot be kept open for more than a short time, except at considerable inconvenience, and, perhaps, great cost to the miner.*

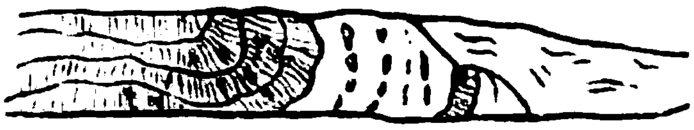

Fig. 55.

Fault, with strata bent up on the upthrow side.

A, The Thick coal squeezed, shattered, and suddenly bent up perpendicularly.

B, The "Grains," and other ironstones usually occurring below the Thick coal, but thinner than ordinary.

C, The Heathen coal, which lies about seven yards below the Thick coal.

D, The red rocks of the Permian formation, much shattered.

Mr. Curwen Salmon, in the year 1862, pointed out to me that there are cases in which the throw of a fault is much greater near the surface than at lower depths, a fact probably explicable either by a change in its inclination, or possibly by some slight tilting of the masses on opposite sides of the fault during the movement, and in the direction of the length of the fault, so that the rise or fall of different parts was not strictly and wholly a vertical one.

When faults traverse very hard and unyielding rocks, such as thick gritstones, hard limestones, or siliceous slates, and still more, if they penetrate igneous rocks, such as granites and felstones, the fissures are apt to be much wider, and often very irregular. If the original fracture shall have taken place not in one plane, but so as to produce two broken or irregular surfaces, with cavities and protuberances as in Fig. 56, and these two surfaces slide one over the other, it is very unlikely that they would ever be made *to fit exactly*, so as to close again entirely upon each other. Protuberance would rest against protuberance, or come against a hollow not large enough, or not of the requisite form, to receive it, and thus the two walls of the fissure would be kept partially and irregularly apart, the fissure being closed

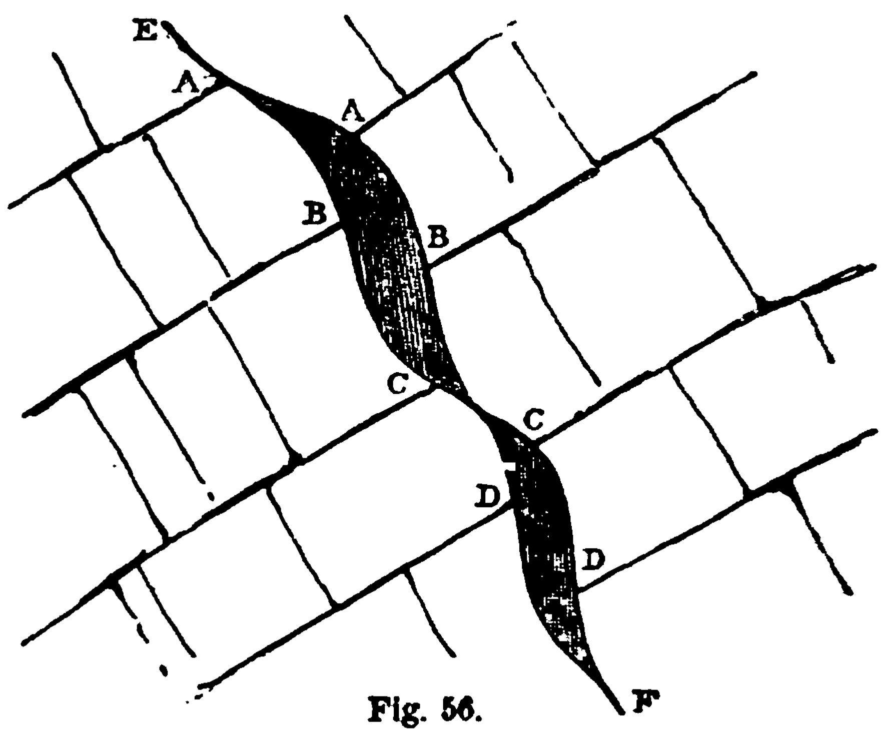

Fig. 56.

Section of hard beds cut by uneven fault, and consequent cavities.

* I was fortunately able to secure for the Coal Commission, which was then sitting, a detailed mining section of this interesting gate-road, constructed with great accuracy by Mr. Hughes of Dudley, mining surveyor, and Mr. Spruce, the manager of the colliery.

It is not very easy, perhaps, to form a correct physical conception of the mode of action of the mechanical forces which produced these and similar phenomena met with in coal-mining, and I believe there is yet much to be learnt by more accurate description and delineation of the phenomena themselves. Geologists must look for information on these and other matters to those practically engaged on them in the future.

in some places and open in others. In Fig. 56 an uneven fracture having traversed the hard beds A B C D, and dislocation taken place, the result would be the irregular fissure E F. It is true that the grinding process, as the surfaces moved upon each other, would often greatly diminish this irregularity, and in soft rocks probably obliterate it; but in hard rocks it is much more usual to find the irregular openings above described still remaining.

Where alternations of hard and soft beds occur, there may be a combination of the two effects, the fissure being quite closed where soft beds are brought together, or even where soft beds are brought against hard, but more or less open where two hard beds come opposite each other. In speaking of open fissures, however, it is by no means intended to assert the frequency of fissures now open and empty. They are almost invariably filled with materials either derived from the ruins of the adjacent rocks at the time of the fracture occurring, or afterwards brought into them.

Some fissures, even in the most yielding rocks, have been kept open, or rather their sides kept apart, by fragments that were dragged into them at the time of their occurrence. In tracing the line of a fault along the surface of the ground in North Wales, I have often found lumps and patches of the broken beds, even some yards in diameter, caught by the way, and serving to point out the direction of the fault.

2. Variation of Faults in effect according to inclination of Beds traversed.

As it is comparatively rare to find beds in a strictly horizontal position over any considerable area, it is necessary to study the effect of faults on inclined beds, and on beds with an inclination varying either in angle, in direction, or in both. If any bed or set of beds "striking" in a given direction, and "dipping" at a given angle, be broken through by a fault, the effect of the vertical "throw" is to produce at the surface the appearance of a lateral "shift" or "heave." Let Fig. 57 be a

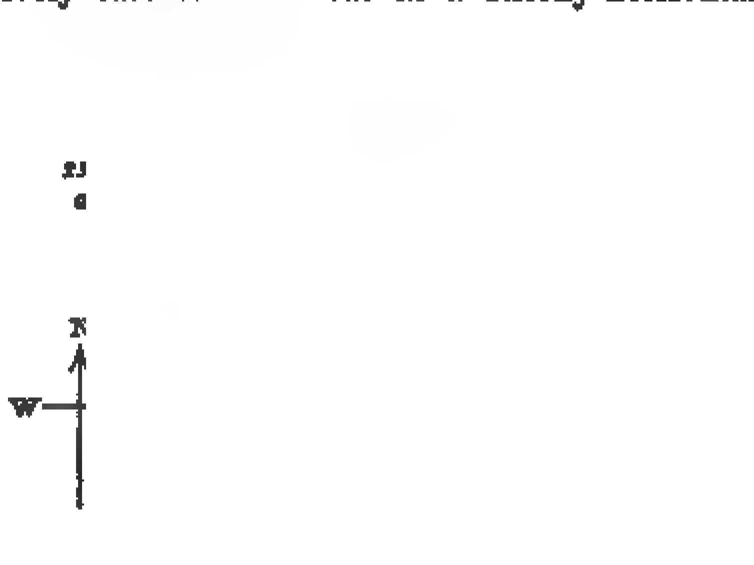

Fig. 57.
Plan of the surface of inclined beds, traversed by a fault which produces an apparent lateral shift.

horizontal plan of the outcrop of a set of beds, of which we may suppose *a a* to be a limestone interstratified with sandstones and shales, and that they all dip steadily to the north at an angle of 25°, and that these beds are traversed by the fault *b b*, causing a "downthrow" to the east, or an "upthrow" to the west, which is the same thing; then the outcrop of the beds will be farther south on the east side of the fault than they are on the west.

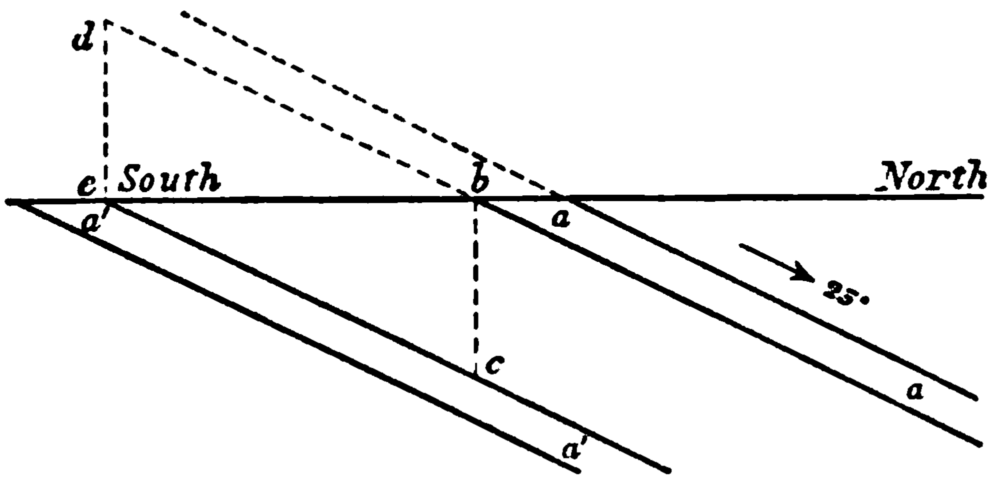

Fig. 58.

Diagrammatic section of Fig. 57, to explain the apparent lateral shift of an inclined bed along a horizontal line when it is moved vertically across it.

To render this more evident, let Fig. 58 be a diagrammatic section drawn from south to north along the direction of the line of fault, showing the beds on both sides of it, and let us look only at the limestone *a a*, disregarding the other beds. If we suppose the part (*b*) dropped vertically down to (*c*), and the part (*d*) in the former continuation of the bed down to (*e*), it is clear that a vertical throw of the bed *a a* on one side of the fault will place it in the position *á á* on the other side of the fault, the respective outcrops of the two pieces of the same bed being at the present surface of the ground at the points *b e*. In other words, the apparently lateral shift of the outcrop of *a a* in the plan, Fig. 57, has been produced by the vertical throw of the inclined beds on opposite sides of the fault. The figure 58 may perhaps be more readily understood if it be copied on a separate piece of tracing paper, and then the tracing paper placed over the figure, so that *á á* should coincide with *d b;* if then the piece of paper be moved vertically down the page, keeping the dotted lines *d e* and *b c* on the tracing paper over those in the woodcut, it will be seen that, while the movement of the paper is vertical, the bed *a a* will travel laterally along the horizontal line from north to south, so that from *b* it will gradually arrive at *e*.

The higher the angle at which the beds dip, the less will be the apparent shift at the surface produced by the same amount of throw. In Fig. 59, the angle of inclination is increased to 60°, the vertical throw, or the distance between *b* and *c*, remains the same as in Fig. 58; but it is obvious that the apparent lateral shift or distance between *b* and *e* is greatly diminished. This diminution would continue with the increase of the angle of inclination, until the beds were actually

vertical, when it is plain that no amount of vertical throw could produce any apparent lateral shifting, for the ends of the beds in the opposite sides of the fault would merely slide up or down along each other. In a set of vertical beds, then, it would be almost impossible to detect a fault, however great may have been the real fissure and dislocation. On the contrary, when the beds lie at a very low angle, a very small dislocation may shift the outcrop of the beds to very considerable distances.

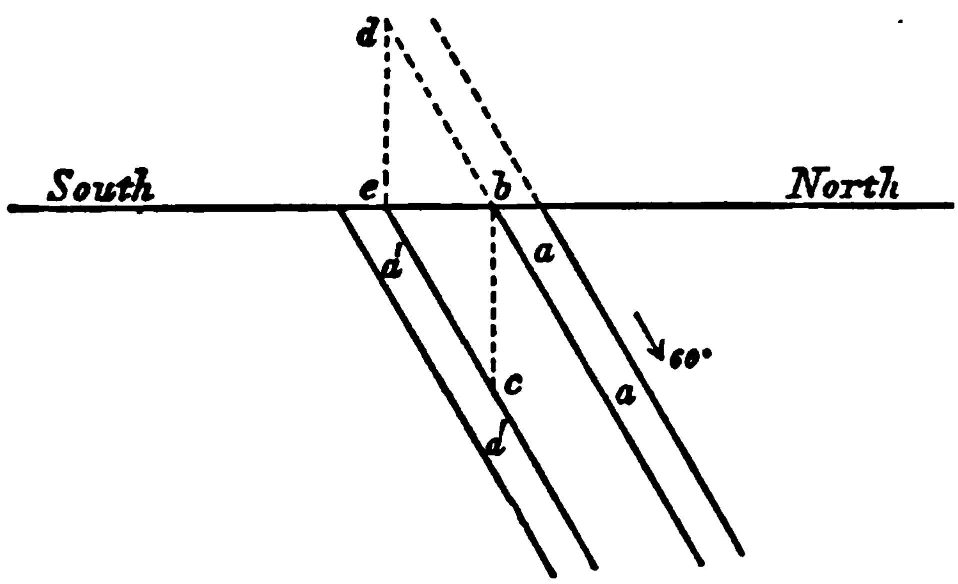

Fig. 59.

It is obvious, from an inspection of Figs. 58 and 59, that if we know the inclination of the beds, and the amount of the vertical "throw" of the fault, we may easily calculate what will be the apparent shift of their outcrop at the surface; and if, therefore, we find the outcrop of one, it will be easy to discover the outcrop of the other. On the other hand, if we know the distance between the outcrop of the beds on opposite sides of the fault, and their angle of inclination, it will be easy to calculate the amount of the vertical "throw," or to discover the depth (or distance, *b c*) at which the one part of the bed will be found lower than the corresponding point on the other side of the fault.

In practice, allowances have to be made for irregularity in the surface of the ground, and for variations in the angle of inclination of the beds, and also for changes in the amount of "throw" in the fault, but in the above consideration of the simplest case lie the elements of much practical utility in mining and other operations. In the Appendix will be found a table, which, among other things, will show the relations between the dip, the throw, and the shift or heave of dislocated beds, pointing out, when any two of these are known, the value of the third.

That this apparent lateral shift at the surface is really due to vertical elevation or depression, may be shown further by examining its effect on beds thrown into anticlinal and synclinal curves. Let Fig. 60 be a plan in which *a a a* is a bed having a synclinal or basin-shaped depression at S S, and an anticlinal form at A A, dipping, as shown by the arrows, at an angle of 60° in each direction, and let it be traversed by the fault F F. It is clear that no lateral shifting will account

for the places of the broken ends of *a a* on opposite sides of the fault, since they are shifted in opposite directions; while their present positions are easily and obviously accounted for on the supposition of a vertical elevation on the side of the fault marked *u u*, or depression on that marked *d d*, and a subsequent planing down of the whole to one level surface. If we draw two sections parallel to the fault, and on opposite sides of it—one, as in Fig. 61, along *u u*, the upcast side, and the other, as in Fig. 62, along *d d*, the downcast side, putting in the beds with a dip of 60°, as directed by the arrows in the plan, we should at once see

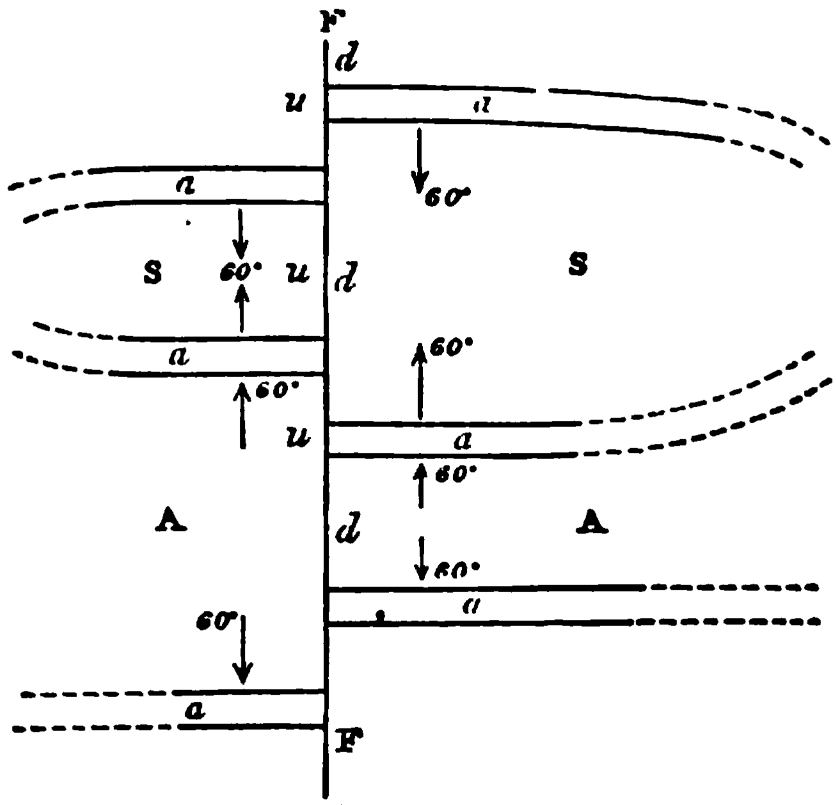

Fig. 60.
Plan of anticlinal and synclinal curve traversed by a fault.

that, in Fig. 61, on the upcast side of the fault, the beds will meet below S, at a point much nearer the surface than they do in Fig. 62 on the downcast side; in other words, that the bottom of the synclinal is at a higher level in the first than the last case. In the same way the point over A, where the anticlinal lines would meet if produced, is higher above the surface in Fig. 61 than in Fig. 62, or the whole of the bed *a a* is more nearly out of the ground in Fig. 61 than in Fig. 62. It is plain that these appearances are the result of the vertical elevation of the beds on one side of the fault F F in Fig. 60, or their vertical depression on the other side of it. The greater the throw, the more widely

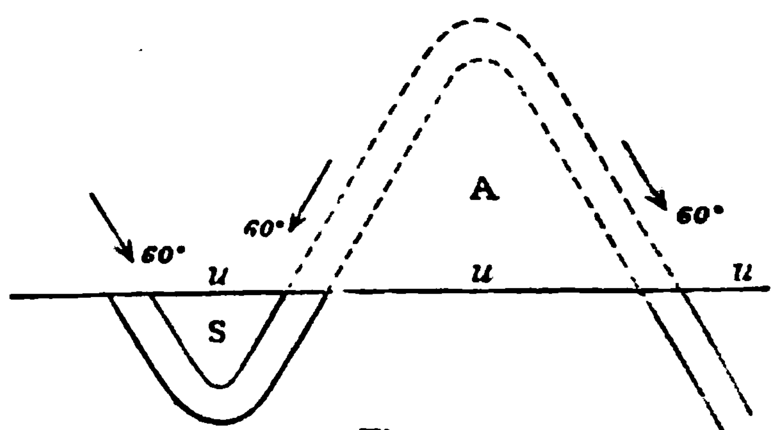

Fig. 61.
Section on the upcast side.

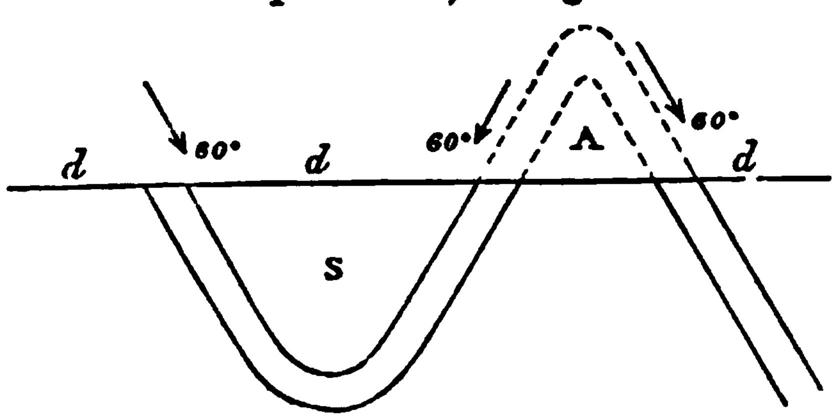

Fig. 62.
Section on the downcast side.

will the outcrops of a synclinal curved bed be separated on the downcast side, and the more nearly will the outcrops of an anticlinal curved bed be brought together, while on the upcast side of the fault the reverse is the case, the outcrops of a synclinal curve will be brought together, and those of an anticlinal will be separated.

When either the angle of the dip or direction of the strike of the beds varies along the course of a fault, its effect upon the position and form of their outcrop becomes equally various. This effect may be still farther complicated by a change in the amount of the "throw" of a fault in different parts of its course.

3. Variation of Faults according to their direction, number, inclination, and combination.

Longitudinal or Strike Faults.—We have hitherto supposed the fault to run directly across the beds, or nearly so, but some faults, either in the whole or in part of their course, run obliquely to the strike of the beds, instead of directly across it, and instances occur of dislocations even running along the strike, so as to entirely conceal some of the beds, as in Fig. 63, which is a plan, where the fault F F, running directly along the strike of the beds, conceals part of No. 2, the whole of 3 and 4, and part of No. 5, as may be seen by the section, Fig. 64.

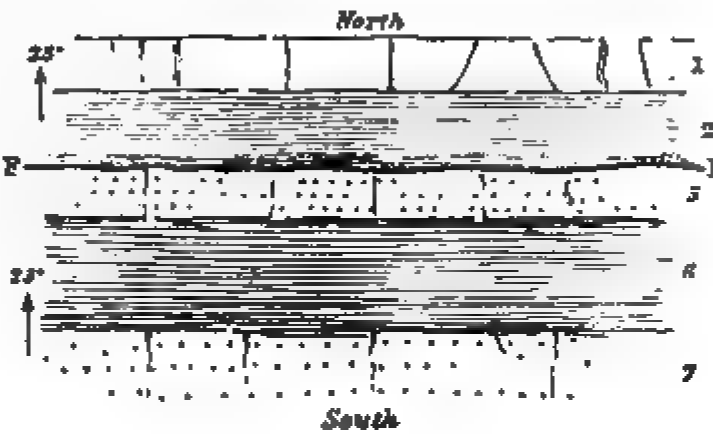

Fig. 63.
Fault along strike. Ground-plan.

There is reason to believe in the existence of *strike-faults* on a larger scale than has yet been suspected. Their detection in countries in which the rocks are greatly disturbed might be very difficult, especially where the true order of succession of the beds is not certainly known, and very

Fig. 64.
Section of Fig. 63.

erroneous conclusions as to that succession might be drawn, since the existence of the faults might be unsuspected until that order had been elsewhere established.

If the magnitude or throw of the strike-fault diminishes in one direction, we should have some of these beds coming out in that direction, as in Fig. 65, and producing a slight variation in the strike of the

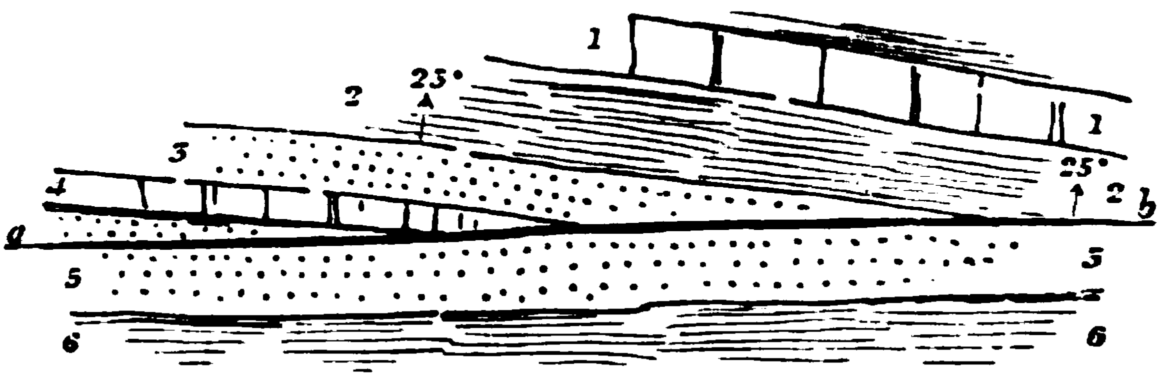

Fig. 65.
Fault along strike, with variation in throw. Ground-plan.

beds. Many other modifications may arise according to the variations in the direction of the faults, with respect to the strike of the beds, or in the amount of their "throw."

Single Faults.—The number and association of faults also requires consideration. If we suppose a single line of fault only to exist, it involves the assumption that the beds have been bent upwards or downwards on one side of the fault, or upwards on one side and downwards on the other. If in Fig. 66 we suppose the line *a b* to be a fissure traversing a set of beds, or if we suppose it to be a crack in a plank of wood, or any other flexible substance, ending each way without meeting with any other crack or fissure, it is obvious that although the parts will be *severed* along it, they will not be shifted vertically unless some bending take place on one side of the fissure, as suggested in Fig. 67. There the beds at *c* are supposed to be bent down, while those at *d* remain fast. Such "single-line faults" have been produced, as is proved in coal-mining. They generally have one, but sometimes more points of maximum "throw" near the centre, and gradually diminish each way till they die out. Not unfrequently they split

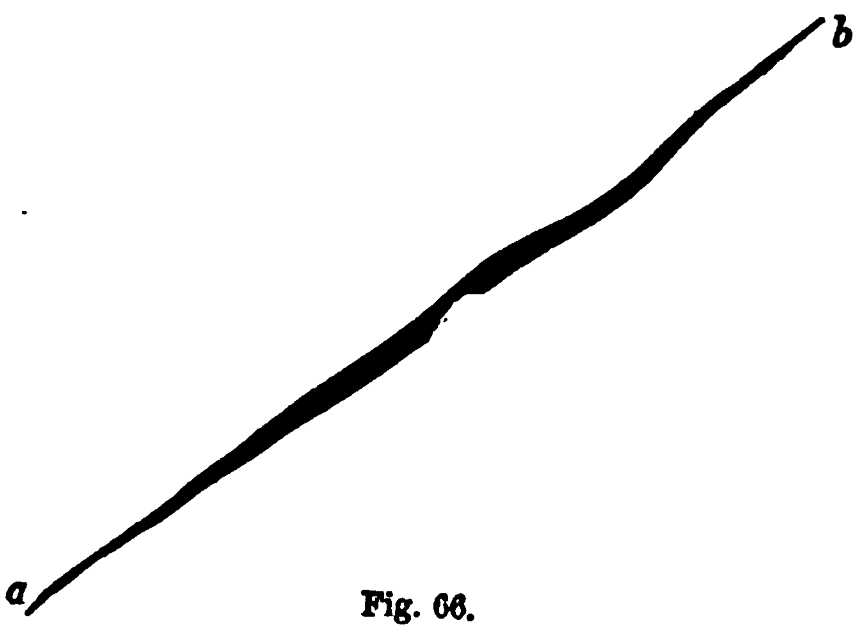

Fig. 66.
Plan of single-lined fault.

towards one or both extremities, as is shown in the plan, Fig. 68, in which the main fault is seen to be split into three at one end and two at the other. The figures represent the amount of the down-throw at each point, in feet, yards, or fathoms, as the case may be. The plan of a fault, given in Fig. 68, is taken from that of the Lanesfield fault in the South Staffordshire coalfield, the figures in that case being yards.

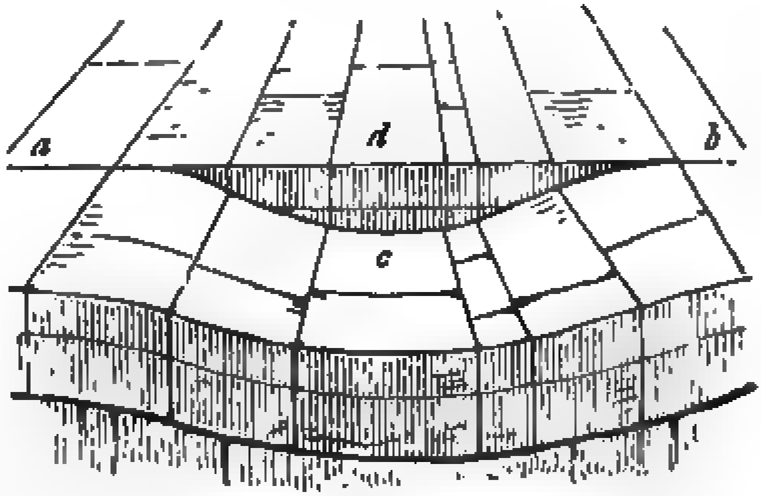

Fig. 67.
Single-line fault, produced by bending of beds on one side of fissure.

It is possible that this bending of the beds along the line of fault may occur more than once, so that they may be thrown into undulations.

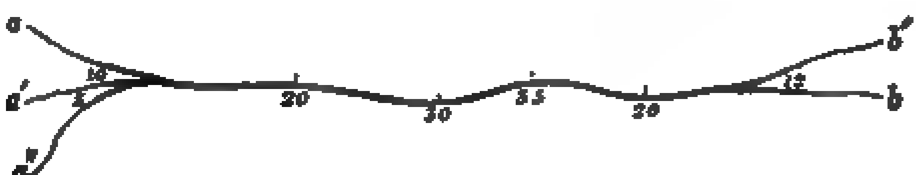

Fig. 68.
Ground-plan of fault splitting at the ends.

This undulation, too, may also become so great that the down-throw may change sides, as is attempted to be shown in Fig. 69. This actually occurs in nature sometimes, the fault appearing to die away when the beds come together, and then to set on again with a dislocation in the opposite direction. The Fig. 69, however, is to be taken as a mere diagram to help the explanation, and not as an actual representation of nature, where the undulations are not so rapid. It must also be recollected that they are rarely apparent at the present

Fig. 69.
Single-lined fault, with alterations of throw produced by undulations of beds along it.

surface of the ground, which, as will be afterwards shown, is in all cases a surface of "denudation" produced by the action of air, stream, the sea, etc., subsequently to the subterranean movements. Single lines of fracture are probably in general much more extensive than the actual dislocated spaces, since such bendings and bulgings as are here shown to be necessary to cause dislocation would be more likely to occur near the central portions of a fracture than near its extremities.

Compound Faults.—When there is more than one line of fracture, the fact of dislocation becomes more easy to understand, since there is no difficulty in conceiving that the angle, or corner of ground included between the intersection of two faults, has been dropped down below, or squeezed up above the corresponding beds on the outside of them. In the plan, Fig. 70, let *a b* and *c b* be two faults meeting in the point *b*, the included part, *d*, being either depressed below, or raised above *a b c*, the maximum movement taking place near *b*. Even in this case, however, the beds on one side or other of the faults must be bent up or down in the direction of *e d*, because if the two faults end or die out at *a* and *c*, and the whole of the beds are on the same level there, one part or other must change that level in proceeding in the direction *e d* towards the point *b*, where the movement was greatest. There is a modification of this case shown in Fig. 71, where we have one long continuous fault A B, with one or more lateral branches, *c d*, *e f*, *i k*, etc., proceeding out of it, or leading

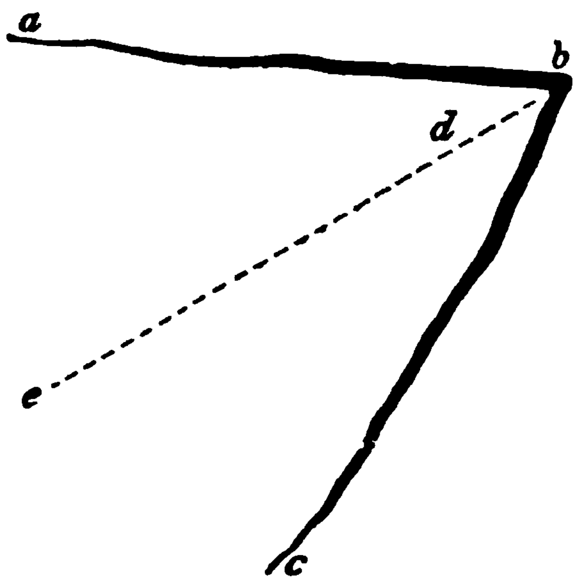

Fig. 70.
Plan of dislocation by two fissures.

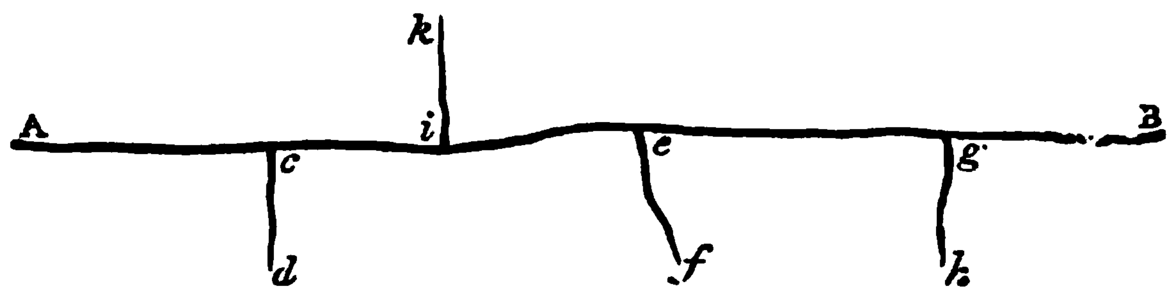

Fig. 71.
Great fault with lateral branches. Plan.

into it, as we may choose to consider them, and either on one or both sides of it. In this case, while the whole mass of ground is thrown on one side of A B, the particular portions between *c d*, *e f*, or the down corners between any one of them and the main fault, may have additional minor dislocations of their own.

Step Faults.—A long powerful fault is often composed in the whole, or part of its course, of a number of parallel fissures, very close together, along a narrow band of country, breaking the rocks into a corresponding number of steps, as in Fig. 72, which either "throw" all in the same direction, or having some steps in opposite directions, produce a balance of "throw" in one direction, so that it is treated as one wide fault.

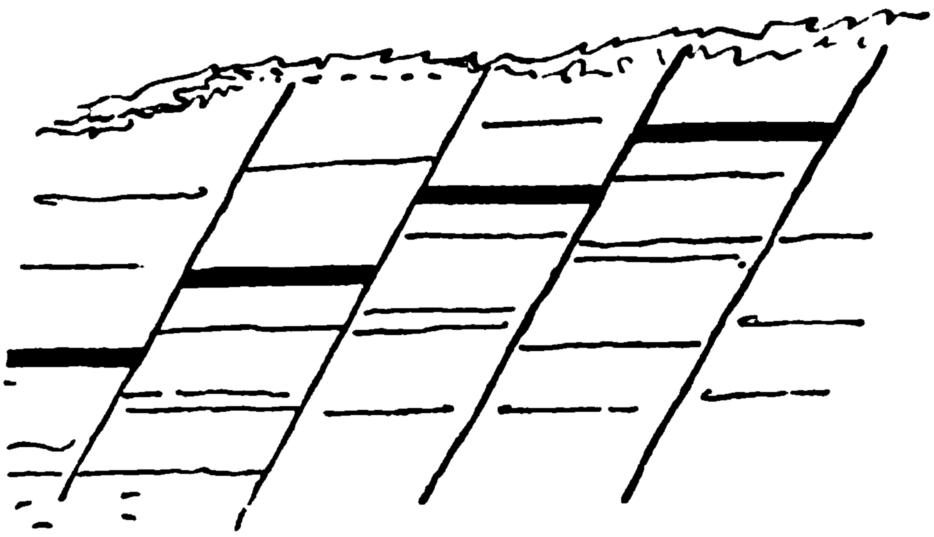

Fig. 72.
Step faults.

In order to have any mass of beds entirely cut off on all sides from those that surround them, and wholly depressed below, or raised above them on every side, it is obviously necessary that we should have at least three straight faults, or two curvilinear faults surrounding the fractured piece of ground. Such completely separated masses of ground let in bodily among a strange set of beds, may perhaps occur in nature, though they are certainly not common.

Relation between the Inclination of a Fault and the Direction of its Throw.—Faults and fissures are sometimes vertical, as at A, Fig. 73, but more commonly inclined at various angles, even so low in some

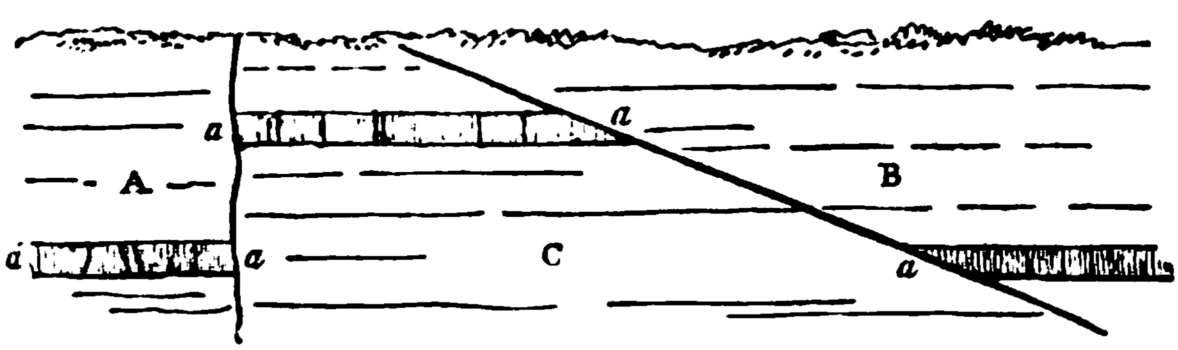

Fig. 73.
Varied inclination of faults, and relation between the "hade" of a fault and the direction of its throw.

instances as 20°, as at B. In speaking of the inclination of a fault, it would have been better not to use the term "dip" as if it were a bed, but to adopt that of "hade" or "underlie," were it not for the fact, which I am indebted to Mr. Curwen Salmon for calling my attention to, that miners generally use the terms "hade" and "underlie" in the sense of an inclination from the vertical. It is therefore the complement of the dip which is the inclination from the horizontal.

If a plane dip at 60° from the horizontal, it will of course "underlie" at 30° from the vertical. In adopting these terms, then, the sense in which they are used must always be specified. In inclined faults, and it almost always happens that faults are inclined, there is one nearly invariable rule, which is, *that the fault "dips," "hades," or "underlies," in the direction of the downthrow.* As a corollary of this rule, also, another equally important one may be stated, namely, that however inclined may be the fault, *no part of any bed will ever be brought vertically under another part of it*, and therefore superior beds can never be brought by a fault under those originally below them. Small exceptions to these rules may sometimes occur in rare instances; when they do, the fault that produces them is called a *reversed fault.*

Reversed Faults.—In Fig. 73, for instance, the fault between B and C hades under the downcast piece of the bed (*a a*); and it is obviously impossible for a vertical fault, or one inclining in the proper direction, to bring any part of the bed *a a* vertically beneath another part, as they would be in the imaginary and exceedingly rare case in Fig. 74.

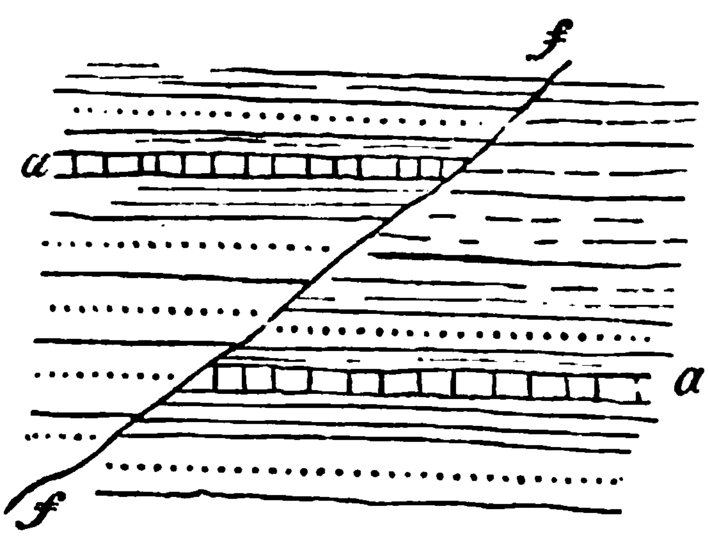

Fig. 74.
Reversed fault; of very rare occurrence.

I have never myself met with any exception to this rule, except on a very small scale, and where it might easily happen that the exception was more apparent than real, the apparent inclination of the fault being merely a local bend in a vertical or nearly vertical fault. A case of real occurrence of a "reversed fault" has, however, been described by Mr. G. H. Kinahan, from the information of Mr. Edge, as to the position of some beds in a colliery in the Queen's County, Ireland,* and other instances have been said to occur elsewhere.

Reason of Rule as to Throw of Faults.—The reason of this rule is sufficiently easy to understand when we come to look at faults on the large scale. Suppose that in the diagram, Fig. 75, we have a section of part of the earth's crust, of which A B is the surface, and C D a deep-seated plane acted on by some force of expansion tending to make the part A B C D bulge upwards. If, then, a fracture take place along the line E F, it is obvious that the expanding force will on the side of A C have the widest base, C F, to act upon, while it will have a proportionately less mass to move in the part A E C F, which grows gradually smaller towards the surface, than on the other side of the

* See *Journal Geol. Soc. Dub.* vol. viii.

fault, where with the smaller base F D, the mass F D B E continually grows larger towards the surface. The mass G will consequently be

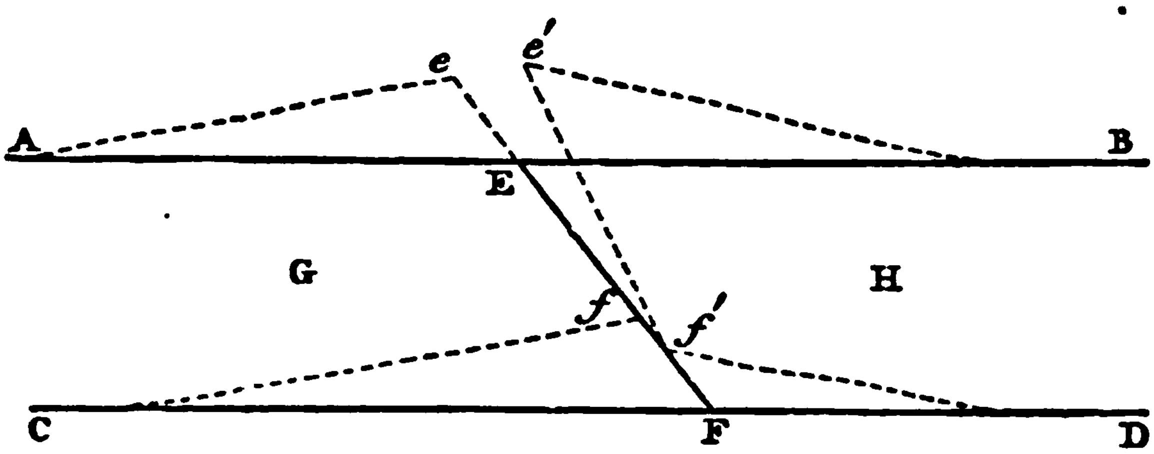

Fig. 75.

much more likely to be raised into the position A *e* C *f*, than the mass H into the position D *f′* B *é*, the elevation of which could hardly take place without leaving a great open gap along the line of fault between F E and *f′ é*, and, moreover, without leaving the projecting piece *é* overhanging without any support.

This is yet more clearly perceptible if we suppose two such fissures, as in Fig. 76, inclining towards each other, since if we suppose the

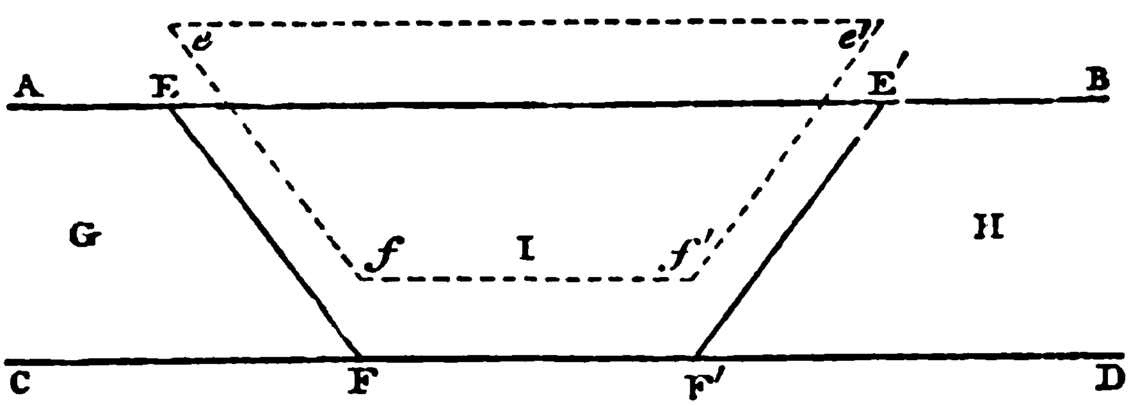

Fig. 76.

included piece I to be elevated into the position indicated by the dotted lines it becomes utterly unsupported ; unless we suppose huge dykes or ejections of igneous rock to issue out along each fault, which would remove the case from the class of fractures we are at present considering.

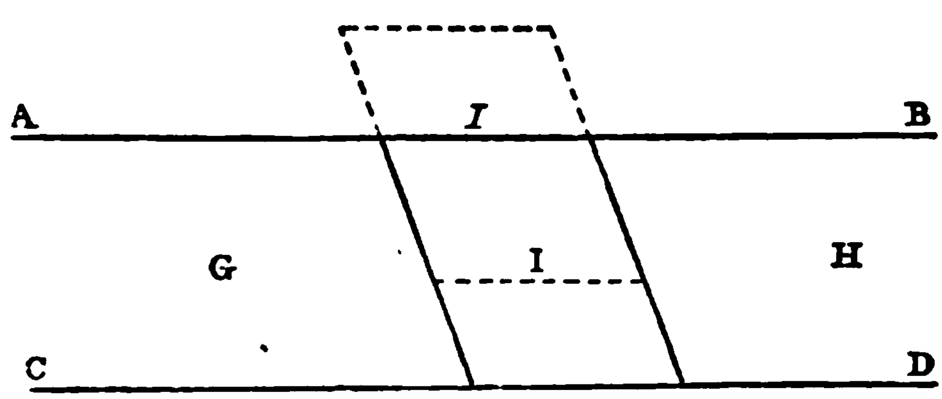

Fig. 77.

In another case which we might imagine, that of two parallel faults inclining in the same direction, as in Fig. 77, the included piece, I, might be elevated without leaving an open fissure, but

then the part *I* would overhang in an unsupported condition, and the enormous friction along two sides of the piece, I, would have to be overcome. I am not aware indeed of any case similar to this having been even supposed by any one.

The late Professor H. D. Rogers,* in describing faults along the axes of anticlinal curves, where inversion has taken place on one side of the anticlinal, spoke of the uninverted part of the anticlinal having been thrust up the inclined plane of the fault, over some of the inverted beds, as in Fig. 73. He did not allude to the fact of this form producing a *reversed* fault, nor is it quite clear in his paper whether the structure thus described has been absolutely observed in sections, or is merely introduced hypothetically as an explanation of certain phenomena. If actually observed, a detailed description of the locality would have been interesting, neither am I prepared to combat the hypothesis, if it be one, since it is just in such greatly disturbed districts that "reversed" faults are likely to occur.

Fig. 73.
Inversion, with reversed fault.

Generalisation of Rule as to Throw of Faults.—I believe that the rule as to the relation between the inclination of a fault and the direction of its throw might be still further generalised, so as to include also the direction of the "heave" or "shift" of the surface outcrop of inclined beds, so that the rule might be stated thus:—"*No fault traversing any set of beds will make an acute angle with the same bed on both sides of the fault.*"

The position of the beds shown in Fig. 74, in which a bed *a a* is cut by a fault F F so as to have an acute angle on both sides of it, is then generally an impossible one (except as a small local occurrence in a greatly disturbed district), whether we regard the figure as a vertical section or a horizontal plan.

Trough Faults.—Faults ordinarily extend indefinitely downwards. We cannot comprehend the possibility of fracture and displacement having taken place in any uncontorted set of beds without all those below having been equally disturbed, unless we come to a part where another fracture occurs, producing an equal amount of displacement in an opposite direction. This junction between two opposite faults pro-

* In his paper on the "Laws of Structure of the more disturbed Zones of the Earth's Crust" (*Trans. Royal Soc. Edin.* vol. xxi. p. 3).

duces what is often called a "trough," the faults being called a "pair of faults." The opposite faults of a trough may be either unequal in "throw," as *a c* and *b c*, in the trough A, or equal, as *d e*, *f e*, in trough

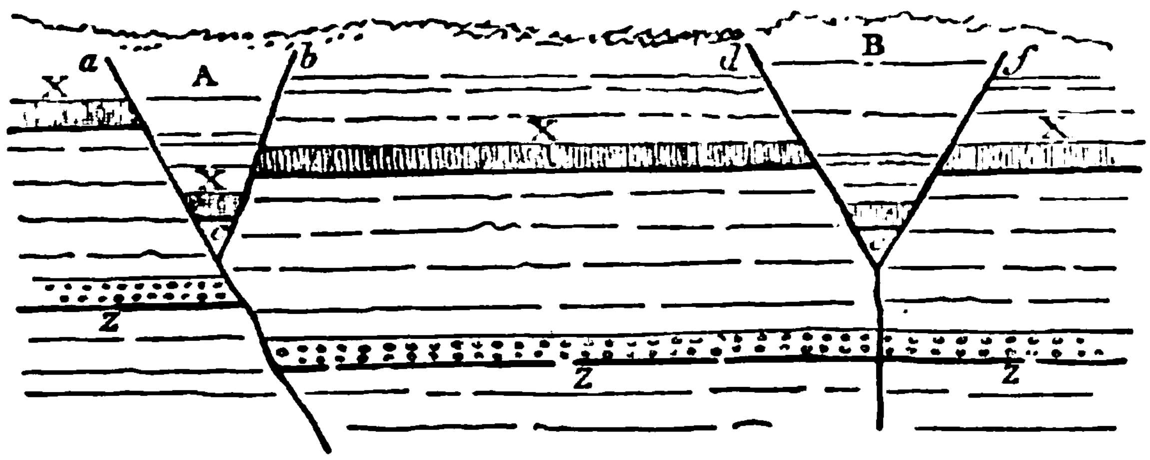

Fig. 79.
Trough faults.

B. In the former case, the displacement affects the whole mass of the surrounding rock, as may be seen by tracing the bed X through the dislocations; in the latter case, it only affects the mass B, which is included between the faults. In the latter case we may see that the bed X on the outside of the trough B is on the same level on both sides.

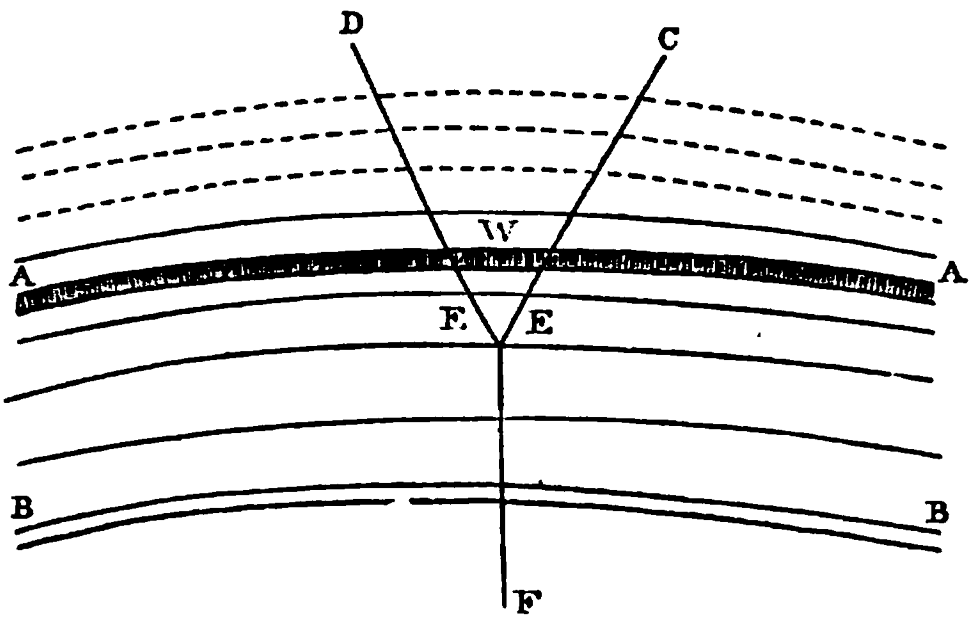

Fig. 80.

The mode of explanation of these trough faults that seems to me the most probable, if not the only one, is the following:—Suppose the beds A A, B B, etc., in Fig. 80, to have been formerly in a state of tension, arising from the bulging tendency of an internal force, and one fissure, F E, to have been formed below, which on its course to the surface splits into two, E D and E C. If the elevatory force were then continued, the wedge-like piece of rock W, between these two fissures, being unsupported, as the rocks on each side separated, would settle down into the gap, as in Fig. 81. If the elevatory action were greater near the fissure than farther from it, the single fissure below would have a tendency to gape upwards, and swallow down the wedge, so that eventually this might settle down, and become fixed at a point much below its previous relative position. Considerable friction and destruction of the rocks, so as to cut off the corner

g h (Fig. 81) on either side, would probably take place along the sides of the fissures, and thus widen the gap, and allow the wedge-shaped piece W to settle down still farther. When the force of elevation ceased to act, the rocks would have a tendency to sink down again and resume their original positions, but these newly included wedge-shaped and other masses would no longer fit into the old spaces, so that great *lateral* compression might then take place.

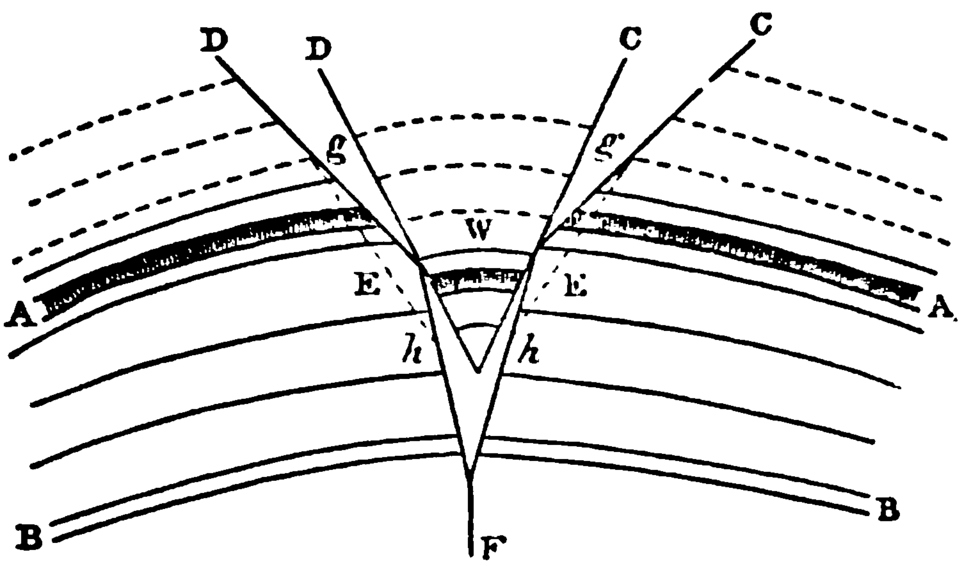

Fig. 81.

The reader must recollect that the Figs. 80 and 81 are mere diagrams to assist his comprehension, and not actual representations, in which there would necessarily be introduced a much greater amount of complexity. This may be seen by an inspection of Fig. 82, which represents the commencement of a trough fault in the middle of the Thick coal of South Staffordshire. This was carefully drawn to scale by Mr. Johnson of Dudley, from the side of a "gate-road" in the Victoria colliery at West Bromwich. It shows the arching of the beds and their fracture by numerous small fissures on each side of the main fracture, where the beds gaped and let in a wedge-shaped piece of the beds above. On each side of this "trough fault" the coal marked B B was reduced by pressure to a state resembling a "paste of coal dust and very small coal," while the parts marked C were uninjured. The total thickness of the coals which here constitute the Thick coal is about ten yards, and the length of the gate-road shown in the figure about 150 yards.*

It seems certain here that the beds were arched and cracked in the centre, so as to include the wedge-shaped mass A, and that on settling down again that piece prevented the beds regaining their former position. The vertical downward tendency then resulting from the pressure of the superincumbent mass would here be transferred to a lateral pressure, tending to crumple and dislocate the beds on each side.

Lateral Pressure.—We have already seen that the appearance of lateral motion having taken place in beds is often a fallacious one. We have, however, in the above considerations, a true cause of lateral pressure, which may sometimes operate on a far larger scale than the little example just quoted. The vast anticlinal and synclinal curves into which great mountain masses are usually thrown may originate in very much the same way† as the minor cracks and squeezes in this case.

* *Mems. Geol. Survey, S. Staff. Coalfield*, 2d edit. p. 194.

† The reasoning above given was worked out during the survey of the South Stafford coalfield in 1847 and 1848. I afterwards observed that Professor Phillips, in his account of the Malvern Hills, in the second volume of the *Memoirs of the Geological Survey*, p. 142, had arrived at similar results by similar reasoning some years before.

Connection between Faults and Contortions.—As the result of my own experience, I may affirm that it is comparatively rare to find a district greatly contorted, and also traversed by large faults; and, on the other hand, wherever a district is much broken by faults, the masses of ground between the faults are usually not much contorted. This is what we should *à priori* expect to be the case, since, if the internal forces of disturbance once break the beds, any further movement will increase the dislocations rather than produce curvatures. It appears likely, also, that deeply-seated contortions will result in fractures of the beds above them, and that one kind of movement will take place in one part, and the other in another part simultaneously. There is, however, nothing unlikely in the supposition that beds contorted at one time may afterwards be fractured.

Vertical Extension of Faults.—We have already seen, in tracing faults superficially along what may be called their lateral extension, that it is impossible to conceive displacement to occur except in consequence of a second fault meeting the first, or in consequence of a bulging of the beds along a part of the line of the fault. Similar reasoning will apply to the vertical extension of a fault. The late Mr. W. Hopkins has shown us that fractures in the crust of the globe have taken place in obedience to certain mechanical laws. If a tract of country of indefinite length and breadth, composed of a set of nearly homogeneous beds, supposed to be originally horizontal, and nearly equally tenacious all over, be acted on by an expansive force from below, such as an elastic gas or a molten fluid would exert, those beds will be strained so as to tend towards bulging upwards, until a number of parallel fissures

Fig. 82.

Section in the Thick coal of South Staffordshire. It illustrates the arched position which was given to the beds, the cracks that were formed in them, and the dislocations that took place, in consequence of the elevation, and as the fractured places endeavoured to settle down on the forces of elevation ceasing to act.

are formed, commencing at points below the surface and running up to it. They may be crossed either then or subsequently by another set of parallel fissures at right angles to the first set. These are the normal results which may, in actual fact, be complicated by many irregularities arising from conditions different from those which were assumed.* It seems to follow from these results, that for displacement to have taken place among the fractured masses, two or more faults should meet below, so as entirely to sever the masses from each other, and allow of unequal motions being communicated to them, or that faults should gradually end downwards on the surfaces of highly curved and contorted beds.

Connection between Intrusion of Igneous Rocks and Production of Faults.—The intrusion of igneous rock may in some instances increase the amount of dislocations; but the student must be on his guard against attributing to local intrusion of igneous rock, effects of elevation, or contortion, or fracture, which are not due to it. The intrusion of igneous rock among other masses is itself a result and not a cause of disturbance. The disturbances of stratified rocks may perhaps be due to widely extended accessions of heat expanding large masses of rock, of all kinds, simultaneously over great spaces, and the subsequent contractions when that heat is diminished or taken away. Small local intrusions of igneous rock may have acted as stays and wedges to prevent the dislocated beds settling back into their former places, but the intrusion of igneous rock during widely spread disturbance seems rather to have been the exception than the rule.

When we come, indeed, to suppose large intrusions of great granitic masses into the rocks above them, we see a fertile source of dislocation, first, by the expansion of the superior rocks from the mere irruption of the bulk of the molten mass, and afterwards from contraction in consequence of the cooling of that mass, which contraction, as we shall see, might amount to even one-fourth of its bulk. Where any large mass of matter, too, has been erupted or ejected over the surface of the ground, the withdrawal of its bulk may have tended to leave a void space in the interior, which, if it were not filled up with other igneous matter, would be followed by subsequent sinkings and dislocations of the rocks over it. As a matter of fact, however, proved distinctly in many cases in the course of the Geological Survey of the United Kingdom, masses of igneous rock, whether contemporaneous with the beds in which they lie, or subsequently intruded into them, existed there before the occurrence of the faults, and have been traversed by those faults, and "thrown" by them, just as much as the aqueous rocks with which they are associated. Nor are these igneous rocks affected by the faults only, but in many cases by the contortions also both on a large and small scale, so as to prove that the contortion did not commence till after the igneous rock was consolidated.

* *Trans. Camb. Phil. Soc.* vol. vi. p. 1.

CHAPTER X.

CLEAVAGE AND FOLIATION.

We have now examined three kinds of divisional planes traversing rock—those, namely, which we might call *congenital*, or planes of lamination and stratification; those which are necessarily *resultant* on consolidation or joint planes; and those which we may term *accidental*, such as faults. There is yet another kind to be described, which we may call *superinduced* planes of division; and these are planes of "cleavage" and "foliation."

Slaty Cleavage.

By "cleavage" or "slaty (or "transverse") cleavage," as it is sometimes called, we understand a tendency in rocks to split into very thin plates, in a certain given direction, independently of any original lamination or stratification of the rocks. It is a structure which is most especially remarkable in clay-slate, but is sometimes apparent in sandstones and limestones, and in some trap rocks. Where it exists it is always most perfect in the finest grained rocks, splitting them into an indefinite number of thin leaves or plates, perfectly smooth and parallel to each other. The coarser the

Fig. 88.

Portrait of a block of variegated slate about 18 inches high, from Devil's Glen, County Wicklow. The crumpled horizontal bands are the beds, the fine perpendicular striæ in front are the cleavage planes, the fine lines on the darkened side merely represent *shadow*, and must not be taken for planes of division in the rock like those in the front which do not pass through the white bands.

rock, the fainter, the wider apart, and the more rough and irregular, do the cleavage planes become. In Fig. 83 is shown a block of slate consisting of alternations of fine purple and rather coarser green and whitish beds, which have been puckered and crumpled. The finer grained and thicker beds are perfectly cleaved by planes cutting directly across them parallel to the dark side of the block, which is itself a cleavage plane, while the coarser parts show less tendency to split in that direction, except at wider irregular intervals.

This cleavage may either coincide with the original lamination of the rock, or cut across it at any angle. When it cuts across the bedding of the rock, the original lamination, or tendency to split along the planes of deposition, is generally obliterated, the laminæ being, as it were, welded together. This cementation of the original lamination is not quite invariably the case. I have met with at least one instance where the rock, an indurated shale, split as readily along the original lamination as along the cleavage planes, and was thus minced into long, needle-shaped spiculæ of slate.*

Transverse cleavage in sandstone usually divides the rock into coarse slabs only, the upper and under surfaces of the sandstone often breaking into dog-toothed indentations. In traversing conglomerates, the cleavage planes leave the pebbles standing out in relief, and do not cut through them as joint planes do.† Cleaved limestone generally has the original bedding greatly obliterated and obscured; the slates which it forms are thick and uneven, and their surfaces often coated by argillaceous films, sometimes giving to the cleavage the exact appearance of bedding. Among trap rocks, some very fine-grained felstones are occasionally affected by cleavage, and fine-grained trappean tuffs are often so affected.‡

In passing through beds of different texture, the cleavage planes often vary their angle a little, having a tendency to cut more perpendicularly across the coarser than the finer grained beds. When the inclination of the cleavage planes and that of the original planes of lamination become nearly coincident in any locality, they sometimes appear to coincide entirely, as if the cleavage went a little out of its way, as it were, to coincide with the bedding.

The finest and largest roofing slates seem to be those of a bluish, grey, or pale-green colour. Where they become either very red or quite black, they are more brittle, and more readily decompose, owing probably to the presence of peroxide of iron in the one, and carbonaceous

* *Report of Geological Survey of Newfoundland*, p. 75.

† Professor Sedgwick.

‡ This is the case with the felspathic porphyry and ashes near the summit of Snowdon, as described and figured by Professor Ramsay in his Memoir on North Wales (*Mem. Geol. Surv.* vol. iii. p. 120); and I have seen beautiful specimens of felstone-slate in County Waterford.

matter in the other. Bands of colour, such as faint red, green, white, or grey, may sometimes be observed on the sides of slates, often coinciding with slight changes of grain or texture. These, which are called the "stripe" of the slate by Professor Sedgwick, mark its original stratification. The bands in the block, which is figured in Fig. 83, show this "stripe" very well. Irregular blotches, however, of different colours, occasionally occur; and sometimes even pretty regular broad bands of colour are to be seen, which do not coincide with the bedding, but go sometimes directly across it, as proved by beds of sandstone interstratified with the slate. Care must be taken, therefore, in field observations, not to rely too implicitly on mere bands of colour in slate rocks, unless they coincide with bands of various texture—that is, layers of finer and coarser grain, which may always be trusted to show the original "layers of deposition" in the rock.

Direction of Cleavage Planes.—The direction of cleavage planes is generally constant over considerable areas, retaining the same compass bearing through whole mountain chains, or across large countries, without paying any regard to the contortions and convolutions of the rocks. One of the best examples of this steady direction in the strike of the cleavage planes is the south of Ireland, over the whole of which, from Dublin to the Mizen Head and the Dingle Promontory, the direction of the cleavage seldom varies 10° from East 25° North, whatever rocks it traverses, and however different these rocks may be in lithological character and geological age. A few local exceptions, in which the cleavage had a strike to the south of east and west of north, have, however, lately been observed.

This steady direction generally coincides with that of the main lines or axes of elevation and disturbance which traverse the district, and consequently with the "strike" of the beds.

In North Wales the strike of the cleavage in the Snowdon chain is generally N.E. and S.W., dipping sometimes to the N.W. and sometimes to the S.E. at high angles (see Fig. 84). Fig. 84 is taken from one in Phillips' Report on Cleavage, in the *Proceedings of the British Association* for 1856, being an extension of one previously given by Professor Sedgwick, running N.W. and S.E. through the Snowdon Chain; the spectator looking N.E. In this section, the beds *c c c* are conglomerates, the other beds being parallel to them, and the fine striæ are cleavage planes striking with the beds to the N.E., but cutting them across in the direction of the dip; for while the beds undulate at various angles, the cleavage dips N.W. at 80° or 85° from A to B; S.E. at 80° to 85° from B to C; and 80° to the N.W. from C to D. In the Berwyn chain, where the beds curve regularly round, from a N.E. and S.W. strike along the Bala and Corwen valley, to an East and West strike along the vale of Llangollen, the strike of the cleavage follows with equal regularity, the cleavage planes dipping W. 20° N. at 30° in the country between Bala and Llangynnog, curving round as they approach Corwen, and striking either due E. and W., or E. 5° N. and W. 5° S., on both sides of the Dee, between Corwen and Llangollen, with a dip almost invariably to the north at a high angle. In a hill called Moel Faen, between Llangollen and the head of the vale of

Clwyd, near Bwlch Rhiwfelyn, the beds are bent into a synclinal curve, so as to dip north on the south side, and south on the north side of the hill; while the cleavage preserves its steady dip to the north at about 60°. The consequence is, that where the dip of the beds and that of the cleavage coincides, the rock makes admirable flags, which are largely quarried; while on the other side, where the cleavage crosses the bedding, slate is produced and quarried for roofing purposes.

Fig. 34.

Section across the Snowdon chain, showing cleavage cutting across beds.*

The inclination of cleavage planes varies from the perpendicular to within a few degrees of the horizontal, but has no apparent reference to the dip of the beds. Mr. Sharpe gives 10° to the W.N.W., as the dip of the cleavage of the Tintagel slate in Cornwall. Round the head of Bantry Bay, the cleavage planes are in some places at as low an angle as 20°, in others are perpendicular, while they everywhere retain the same strike of about E.N.E. and W.S.W.

Professor Sedgwick was the first to systematically observe and describe the phenomena of slaty cleavage.* In the third of the publications mentioned below, he gives the following as the results at which he had arrived :—

"1st, That the strike of the cleavage planes, when they were well developed, and passed through well-defined mountain ridges, was nearly coincident with the strike of the beds.

"2d, That the dip of these planes (whether in quantity or direction) was not regulated by the dip of the beds, inasmuch as the cleavage planes would often remain unchanged, while they passed through beds that changed their prevailing dip or were contorted.

"3d, That where the features of the country or the strike of the beds

* His observations will be found in the *Transactions of the Geological Society*, vol. iii., on "The Structure of large Mineral Masses," and also in his *Introduction to a Synopsis of the British Palæozoic Rocks*, 3d Fasciculus, p. 33.

were ill defined, the strike of the cleavage became also ill defined, so as sometimes to be inclined to the strike of the beds at a considerable angle.

"4th, Lastly, that in all cases where the cleavage planes were well developed among the finer slate rocks, they had produced a new arrangement of the minutest particles of the bed through which they pass."

Origin of Cleavage.—One of the most striking effects of cleavage is the distortion it produces on fossils or other small bodies embedded in the rocks, lengthening and pulling them, as it were, in the direction of the cleavage, and contracting them in the opposite direction. Relying on these facts, which were first distinctly noticed by Professor Phillips, Mr. Sharpe attributed the production of cleavage to the action of great forces of compression squeezing the particles of rock in one direction, and lengthening them in the opposite.* Mr. Darwin, also, from his observations in South America, formed similar ideas as to the origin of cleavage, and speaks of cleavage planes as being probably parts of great curves, of such large radius as that any portions of them that can be seen at one view appear to be straight. More recently, Mr. Sorby, resting on the fact that beds of sandstone which occur in slate are contorted, and their thickness contracted at the sides and expanded at the tops and bottoms of the curves, the axes of which curves coincide in direction with the cleavage planes, while the beds of slate above the sandstone are little if at all bent, maintains that the particles of the slates must have been compressed at right angles to the cleavage planes, and lengthened along them, so as to allow of their being squeezed into the same contracted space as the contorted sandstones, without much bending of their own bedding planes.†

By microscopical examination, Mr. Sorby found that the minute particles of clay-slate were either lengthened in the direction of the cleavage planes, or that those minute particles, which were of unequal dimensions, were so re-arranged as that their longer dimensions coincided with the planes of the cleavage. He did not suppose that the existence of peculiarly shaped particles was necessary to the production of cleavage, he merely used them as tests to show that the particles had been re-arranged by the action of the pressure to which he attributed the cleavage. Dr. Tyndall subsequently investigated the subject, and produced perfect slaty cleavage artificially, in clay and white wax, and other substances, by subjecting them to pressure under conditions which allowed of their expansion in directions at right angles to the pressure.‡

* *Quarterly Journal Geological Society*, vol. iii. p. 87.

† See *New Philosophical Journal*, 1853, vol. lv., p. 137; and Lyell's *Elements*, 6th edition, p. 742.

‡ His results are given in the *Philosophical Magazine*, vol. xii., and in a lecture to the

Professor Sedgwick at one time thought that he could perceive a tendency to a symmetrical arrangement of the inclination of the planes of cleavage with respect to the axes of lines of elevation, the dip of the cleavage being inwards on each side of the mountain ranges. He afterwards, however, saw reason to abandon this conclusion. Mr. Darwin speaks of the fan-like arrangements of the cleavage planes which have been described by Von Buch, Studer, and others; and Mr. Sharpe says that this apparent fan-like arrangement is due to parts of two contiguous curves meeting where their adjacent sides become perpendicular.*

The prevailing opinion now among those natural philosophers, to whom, of course, geologists must look as authorities, is that Slaty Cleavage is the result of the mechanical forces that have acted upon the crust of the earth. Mechanical force and chemical action, however, are often so intimately connected, that the latter may often have accompanied or followed the former in this as in other cases.

Time of Production of Cleavage.—Slate occurs chiefly in or near to mountain chains, or places which have the structure if not the altitude of mountains, and is found in all parts of the world, and in formations of all geological age. In the British Islands, indeed, slate is found almost solely in the Palæozoic rocks, but the Andes of Chili and Tierra del Fuego contain clay-slate of Cretaceous age, and the black slates of Glarus in Switzerland, which are formed by as true a slaty cleavage as any in Wales, are of still more recent date.

Surface Disturbance of Cleavage Planes.—The dip of the cleavage may be easily mistaken, unless it be observed in deep excavations. Superficial causes have frequently affected and sometimes completely inverted it to very considerable depths, as shown in Fig. 85, and even to a much greater extent than is there delineated.

When these superficial bendings of slate occur on steeply inclined ground, they may perhaps be referred to the action of gravitation on substances loosened by weathering, or the "weight of the hill," as it has been called. In other cases, their origin is more obscure, and I have seen, at least, one instance in North Wales, where, on the horizontal surface of an isolated boss of rock, the slates were so sharply and abruptly bent back and laid nearly flat, and partly consolidated in that position, as to give the idea of its being due to some sudden and great

Royal Institution, since published in the appendix to his work on *The Glaciers of the Alps*. In a paper in the same volume of the *Philosophical Magazine* Professor Haughton has deduced mathematically a value for the compression of the rocks, from examining the amount of distortion suffered by fossils in some particular instances in consequence of this compression.

* We must refer the reader to his papers on this subject, in the third and fifth volumes of the *Journal of the Geological Society* before quoted, and in the *Philosophical Transactions* for 1852. In the *Proceedings of the British Association* for 1856 will be found the first part of a Report by Professor Phillips on this subject.

force, such as the grounding of an iceberg.* I have more lately observed in Devonshire, where it has been much noted by Sir H. De la

Fig. 86.
Surface bending of cleavage planes.

Beche, in one or two places the upper part of some slates thus abruptly bent back into a horizontal position for a depth of several feet from the surface. They were always bent down the hill, but the slope of the ground was not steep. Neither is there any constancy in the direction of this surface bending of slates, as has been recently asserted, for in a recent excursion in South Devon I saw as many cases of the slates being superficially bent to the north down a hill, the slope of which was inclined in that direction, as in any other.

Foliation.

The technical meaning of this term, originally suggested by Professor Sedgwick in his paper on the "Mineral Structure of Large Masses," before referred to, and since adopted by Mr. Darwin in his volume on the "Geology of South America," is a "separation into crystalline layers of different mineral composition," while cleavage means only a "tendency to split" in a mass of the same composition. Foliation, however, even when it coincides with the original lamination of a bed, is nevertheless a superinduced structure.

In examining a specimen of a true schist or foliated rock, and comparing it with one of shale made of the same materials, arranged in laminæ merely by the act of deposition, the difference is at once perceptible, although it is not easily described in words. In mica-schist

* Without intending to impeach the accuracy of any recorded observations, I yet cannot feel sure that many even of my own registered observations on cleavage in different localities may not be affected by errors of the kinds alluded to above.

the mica occurs not in small distinct spangles, but in continuous "folia," with an unbroken micaceous lustre and structure over the whole surface of the layer.

In gneiss the rock has a firmer texture, and a more crystalline aspect. Sometimes even large distinct crystals of one or other mineral traverse the folia, and occasionally the foliation is more or less lost in and obliterated by the further development of the crystalline structure. Professor Sedgwick is of opinion that the foliation usually coincides with the cleavage, and is merely a further development of the same process, an opinion in which he is supported by Mr. Darwin and the late Mr. Sharpe. In speaking of cleavage, he says that in many cases the cleavage laminæ "are coated over with chlorite and semi-crystalline matter, which not merely define the planes in question, but strike in parallel flakes through the whole mass of the rock."

Mr. Darwin's Observations on the Foliation of S. America.—Mr. Darwin * has some excellent remarks upon this subject. He says (p. 163)—"The fact of the cleavage laminæ in the clay-slate of Tierra del Fuego, when seen cutting straight through the planes of stratification, differing slightly in colour, texture, and hardness, appears to me very interesting." He observed in Chili, "some distinct thin layers of epidote, parallel to the highly inclined cleavage of the mass." He then goes on to remark, with respect to the foliation, "as in the case of cleavage laminæ, the folia preserve over very large areas a uniform strike, thus Humboldt † found for a distance of 300 miles in Venezuela, and indeed over a much larger space, gneiss, granite, mica, and clay-slate, striking very uniformly N.E. and S.W., and dipping at an angle of between 60° and 70° to N.W.,—it would even appear from the facts given in this chapter, that the metamorphic rocks throughout the north-eastern parts of South America are generally foliated within two points of N.E. and S.W. Over the eastern parts of Banda Oriental, the foliation strikes with a high inclination very uniformly N.N.E. to S.S.W., and over the western parts in a W. by N. and E. by S. line. For a space of 300 miles on the shores of the Chonos and Chiloe Islands, the foliation seldom deviates more than a point of the compass, from a N. 19° W., and S. 19° E., strike." He then proceeds to state, that the angle of the dip in the foliated rocks is generally high, but variable, sometimes on one, sometimes on the other side of the line of strike, and sometimes vertical, and adds—

"On the flanks of the mountains, both in Tierra del Fuego and other countries, I have observed that the cleavage planes frequently dip at a high angle inwards; and this was long ago observed by Von Buch to be the case in Norway; this fact is perhaps analogous to the folded fan-like or radiating structure in the metamorphic schists of the Alps, ‡ in which the folia in the central crests are vertical, and on the two flanks inclined inwards. Where masses of fissile and foliated rocks alternate together, the cleavage and foliation, in all cases which I have seen, are parallel. Where, in one district, the rocks are fissile, and in another adjoining district they are foliated, the planes of cleavage and foliation are likewise generally parallel."

He sums up his observations as follows:—"Seeing, then, that foliated schists indisputably are sometimes produced by the metamorphosis of homogeneous fissile rocks; seeing that foliation and cleavage are so closely analogous in the several

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* In the sixth chapter of his *Geological Observations on South America*, p. 163.

† *Personal Narrative*, vol. vi., p. 591, *et seq.*

‡ Studer, in *Edin. New Phil. Journal*, vol. xxiii., p. 144.

above enumerated respects; seeing that some fissile and almost homogeneous rocks show incipient mineralogical changes along the planes of their cleavage, and that other rocks with a fissile structure alternate with and pass into varieties with a foliated structure, I cannot doubt that in most cases foliation and cleavage are parts of the same process; in cleavage there being only an incipient separation of the constituent minerals, in foliation a much more complete separation and crystallisation."* Mr. Darwin afterwards seems inclined to refer some of the apparent stratification of metamorphic schists, or their separation into alternating beds of different mineral composition, to a still further development of the foliating process, though he, of course, does not extend this so far as to include the production of "thick beds of marble," or other distinct rock.

Difference between Cleavage and Foliation.—It would be with unaffected diffidence that I should venture to differ from such a high authority as Mr. Darwin, more especially on a point in which he agrees with my own old master and teacher Professor Sedgwick. I may however, perhaps, be allowed to suggest the possibility that the connection between cleavage and foliation, in such cases as those mentioned by Mr. Darwin; may be a proof of their coincidence rather than of

Fig. 86.

Foliation of mica-schist, coincident with bedding. Ardmarnock, Loch Fyne. Sketched by Mr. Geikie.

The fine wavy lines show the foliation of the schist, and the thicker white bands are beds of greywacke interstratified with the schist, and proving that the original bedding of the rocks and the superinduced foliation coincide in direction.

their identity. If rocks already cleaved are acted upon by any agency tending to metamorphose them, and rearrange their particles in separate folia, that rearrangement may in some cases take place along the cleavage planes, and in others along those of original lamination.† It may

* *Op. cit.* pp. 165-6.

† See Ramsay, *Quart. Jour. Geol. Soc.*, vol. ix. (1853), p. 172.

even happen that in some districts both cases may occur, and both, perhaps, may be mingled in such a way as not to be readily distinguishable where the metamorphism has become very complete. Moreover, since the cleavage planes usually strike with the principal axis of elevation, and the beds, especially when they approach the vertical position, have necessarily the same general strike, it follows that the cleavage and foliation must necessarily be generally parallel to each other, whether the folia coincide with the cleavage or the stratification. Observations as to the vast thickness of such groups of rock may often be deceptive, since concealed anticlinal and synclinal curves frequently occur in them, the beds being either vertical or inclined in the same direction, on account of one or the other side of the curves being inverted, and the folds often sharp, and either not occurring just at the present surface, or occurring in places where the rocks do not happen to be exposed at the surface. From the observations of Sir Roderick Murchison and Mr. Geikie, it appears that in the Highlands of Scotland, where metamorphism has been developed on a great scale, the foliation is coincident with the original stratification of the rocks. (See Fig. 86.) This is shown by the intercalation of fossiliferous quartz rocks and limestones among the gneissose rocks, the foliation in the latter coinciding with the dip and strike of the former.*

Cleaved and Foliated Rocks of the Leinster district.—Districts where the metamorphic action has been very great and very widely spread, such as those of S. America, of the Highlands of Scotland, of Scandinavia or the Central Alps, may be less instructive than others, where the alteration having taken place to a less extent, and on a smaller scale, its nature may be the more readily grasped.

Such a district we have in the south-east of Ireland, where one great mass of granite has been intruded into the clay-slates of the district, forming a continuous range of granite hills from Dublin Bay to the neighbourhood of New Ross, a distance of 70 miles. Between this range and the coast other smaller intrusive bosses of granite make their appearance at the surface through the clay-slate rocks. The clay-slates are generally dark-grey, blue, or black, but sometimes pale green or greenish grey, with occasionally red or purple bands. They are generally of a dull earthy texture and without lustre. Small bands of grey cross-grained siliceous grit frequently occur in them. Wherever the granite comes to the surface, a belt of slates surrounding it is converted into mica-schist, with, in some few places, beds of rock that might be called gneiss. Crystals of garnet, schorl, andalusite, staurolite, etc., sometimes make their appearance in certain beds of these altered slates where they closely approach the granite. The width of the metamorphosed belt is generally proportioned to the size of the granite mass which it surrounds. Round the smaller granite bosses it is sometimes not more than fifty yards wide; round the main granite mass it sometimes reaches to two miles.

In going towards the main granite ridge, it is found, sometimes at a distance of two miles from the outcrop of the granite (which is, however, much nearer, probably, in a vertical direction), that the slates have acquired a "glaze," or micaceous lustre, with a soapy feel. This lustre is apparent throughout the mass when the slates are broken, and even when they are ground down into sand or

* Murchison and Geikie, *Quart. Jour. Geol. Soc.*, vol. xvii. D. Forbes, *op. cit.* vol. xi. p. 166.

powder. The micaceous appearance increases as we approach the granite, till at last the whole assumes the ordinary character of mica-schist. The small interstratified bands of siliceous grit, however, show no more appearance of crystallisation or micacisation, even when in contact with the granite, than they do at a distance of two or three miles from it, although the grey slates interstratified with them may be converted into the most glittering silvery mica-schist. Together with the micaceous lustre on the surface of the slates, the rocks often assume the puckered and corrugated texture of mica-schist. I at one time thought that this corrugation might be due to metamorphism, like the foliation, till I found that the small bands of unaltered siliceous grit were often equally corrugated. The crumpling, then, must be ascribed simply to a mechanical force compressing the rock laterally. In the great majority of instances, the folia of the mica-schist, whether straight or puckered, are certainly parallel to the grit bands, and therefore to the original lamination and stratification of the rock.

Some of the gneissose beds about Polmounty, near New Ross, had all the appearance of interstratified beds of shale and sandstone at a distance, and until they were broken open and found to be perfect mica-schist and gneiss. Other gneissose beds were massive and thick-bedded, and contained large crystals of felspar (apparently orthoclase) becoming quite porphyritic, but still having a foliation parallel to what is apparently the original stratification of the mass, which in one conspicuous instance (near Graiguenamanagh) is nearly horizontal.* In this instance, then, the foliation was clearly developed along the lamination of the rocks, and had only an occasional and accidental coincidence with the cleavage. Good slaty cleavage was observed in the clay-slates immediately outside of the metamorphosed band in one or two places, without showing any appearance of foliation; and not differing from the slaty cleavage seen at a distance from the granite.

Foliation of Anglesey.—The 3d vol. of the *Memoirs of the Geological Survey* contains a memoir on North Wales, by Professor Ramsay, in which the student will find some interesting "Observations on the Metamorphism of the Rocks of Anglesey." † He points out, as Mr. Sorby had previously done, that the foliation may also coincide with the "obliquè lamination" or "false bedding" of a rock, and thus appear to cross the planes of stratification and yet not be coincident with any previous cleavage. He also describes and gives illustrative sketches of the many curious contortions in the rocks of Anglesey, and their relations to the foliation of the metamorphosed rocks, showing that it is often difficult, if not impossible, to determine these relations with anything like certainty. "Stratification, foliation, and cleavage," he says, "are, perhaps, all and each often sufficiently distinct; but, again, they are sometimes inseparable, or, in other words, it is difficult to say if foliation and bedding coincide, or foliation and cleavage, or if the foliation has nothing to do with either." ‡

The student must always bear in mind, when making observations on cleaved and foliated rocks, or in reasoning on the modes in which these structures have been produced, that although the rocks which show them are now at the surface, they were deeply buried, at the time they were thus affected, under a thick cover of rock which has since been removed. There is one curious line of inquiry respecting foliation and cleavage, which is hinted at by Professor Ramsay in the passages of his *Memoir* quoted from above, and that is the various geological periods during which the different rocks that show them were so affected as to have these structures produced in them in different places. This inquiry cannot be followed out

* See Explanation of Sheets 147 and 157 of the Geological Maps of Ireland.

† *Mem. Geol. Surv.*, vol. iii., p. 177, *et seq.* ‡ *Op. cit.*, p. 180.

here, since it is one which involves a knowledge of geological chronology which we have not yet entered on, and it is one for the professed geologist rather than the student.

Foliation has been referred to in this chapter as a structure developed in rocks subsequent to their formation. It occurs therefore only in metamorphic districts, and is intimately associated with the process of metamorphism. What the nature of that process is falls to be treated in the next section of this Manual, and we shall then have occasion to recur to the subject of foliation, and the causes to which its origin is to be ascribed.

CHAPTER XI.

UNCONFORMABILITY AND OVERLAP.

Unconformability arises from a surface of "Denudation" * having been formed on one set of beds before the deposition of another set upon them. When one group of beds rests upon the denuded edges of another group, the upper is said to be unconformable to the lower group. In most cases the lower group has been tilted before the edges of its beds were "denuded," or worn away, so that there will be a marked difference in the "lie" of the two sets of rocks. The commonly received idea of unconformability refers solely to this difference in their "lie," but that difference is not essential, since two unconformable sets of beds may both remain horizontal, or be subsequently tilted, so that both may dip at the same angle in the same direction. The most general statement of what constitutes unconformability is—*When the base of one set of beds rests in different places on different parts of another set of beds, the two are unconformable to each other.*

For unconformability to arise, then, there must be two different sets or groups of beds which had an interval between their periods of production, that interval being marked by a greater or less denudation of the older set. **Overlap**, on the other hand, takes place only in the same set of beds, or in different sets of the same conformable series.

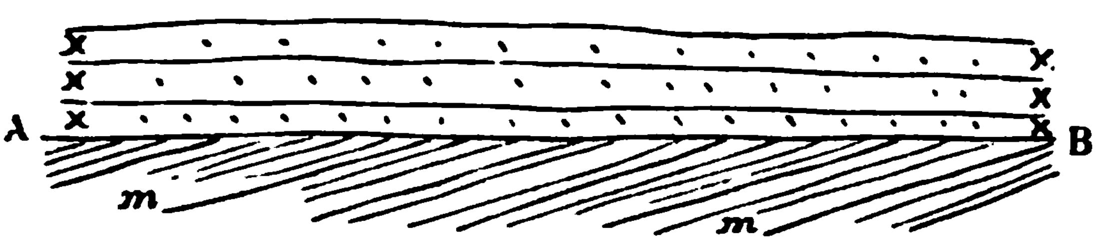

Fig. 87.
Simple unconformability.

In Fig. 87 we have represented one of the simplest cases of unconformability, in which the lower groups of beds *m m* have been uptilted and denuded, so as to form the horizontal surface A B, on which the

* It is impossible adequately to comprehend what is implied in unconformability unless the student has formed a proper notion of what is meant by denudation. He may refer for details regarding the latter subject to the next section (on Geological Agencies), where it is discussed in reference to the causes by which it has been produced.

beds X X have been deposited. The lower set of beds, however, may have had their edges denuded without being tilted from the horizontal, or at all events having so close an approximation to horizontality at the time of the deposition of the superincumbent beds, that no sensible difference is now to be detected in the "lie" of the two groups in the places where they are exposed. Fig. 88 will serve to explain this case,

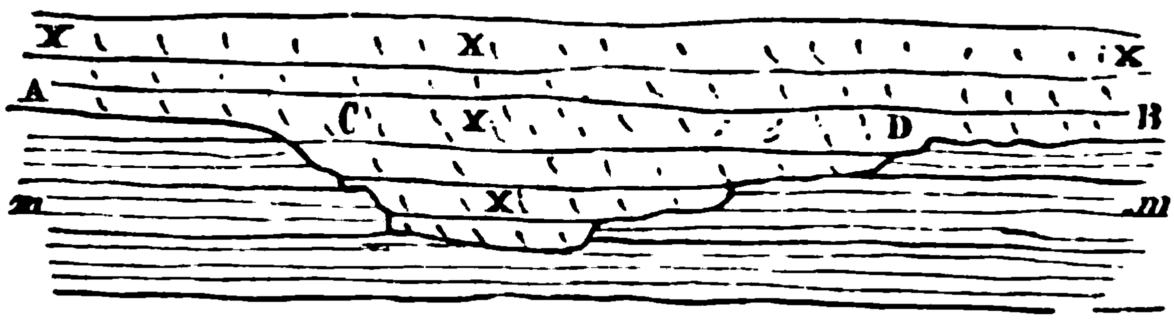

Fig. 88.

in which the beds *m m* still remaining horizontal have had their surface A B worn in some places into hollows and cliffs, in or against which the beds X X have been deposited. If these two sets of beds chance to be exposed in places where the surface A B happened to be horizontal at the time of the deposition of X X, as in the parts between A C or D B, their unconformability may not be at first perceived. An example of this case was found in the South Staffordshire coalfield, where the beds X X are represented by the Coal-measures, and the beds *m m* by the Silurian rocks.* It is necessary, however, if the beds remain horizontal, that the *surface* of the lower set should in some places be inclined; while, if the beds are inclined, the surface may be horizontal, or may cut across their edges at any angle or in any direction.

Cases occur of apparent unconformability between different portions of the same set of beds. These have been spoken of as "Symon faults" when met with in the Coal-measures.† I believe, however, that these are larger examples of what I have already described as *contemporaneous erosion and filling up.*‡ The distinction between them and true unconformability I believe to be this, that the surface of erosion in their cases was produced merely by local currents in the water in which the beds were being deposited, while for true unconformability it is essential for the beds to be lifted into dry land, before either atmospheric, or even marine denudation can produce a new surface on them generally, for the sea can only produce such an effect by its breakers acting on the edge of a dry land.

* See *Mem. of Geol. Survey*, Geology of S. Staff. Coalfield, 2d edit. p. 80.

† One excellent case, in the Shropshire coalfield, has been described by Mr. Prestwick in the 5th vol. of the 2d series of the *Trans. Geol. Soc. Lond.*, and again, in more detail, by Mr. Scott in the 17th vol. of the *Journal* of that Society.

‡ See *ante*, p. 164.

Successive Unconformabilities in South of Ireland.*—Very complicated cases of unconformability are to be found in some places, especially among the older rocks. In the south of Ireland, for instance, there are cases in which the Lower Silurian beds rest unconformably on the denuded edges of the older Cambrian rocks, while they present a widely denuded surface for the reception of the Carboniferous formation. These likewise not only rest unconformably on the Lower Silurian beds, but are themselves greatly disturbed and denuded, so that we have, within a small area, proofs of three several periods of the elevation of sea-formed rocks into dry land, and of the denudation of their surface, each elevation having gone the extreme length of placing the rocks in some parts into the vertical position.

Fig. 89 is a section near Ashford, in County Wicklow, showing the unconform-

Fig. 89.

Section from south to north across the Devil's Glen and Ballycullen Hill, near Ashford, County Wicklow.

ability of the Lower Silurian, marked S S, on the Cambrian beds, marked C C.

Fig. 90.

Sketch of the cliffs on the north side of the River Suir, opposite the town of Waterford.

Fig. 90 is one of almost innumerable sketches that might be given in which the

* I hope that the fact that many of the following examples are taken from Irish localities will not lead the student to suppose that the principles deduced are only applicable to that country. I have taken Irish examples partly from a reluctance to trespass on other persons' territories, and go beyond the limits of the domain which fortune has assigned to me for the last seventeen years. Numerous examples may easily be deduced from the study of the geological maps and sections of Great Britain and other parts of the world.

[The first careful examination and description of unconformability appear to have been those of the illustrious Hutton among the palæozoic rocks of Scotland. The student should not fail to read the classic account of these researches, given by Playfair in his Illustrations of the Huttonian theory, and in his beautiful Life of Hutton. (*Works*, vol. iv.)]

unconformability of the Old Red Sandstone to the Lower Silurian is plainly observable. It is from a sketch by Mr. Du Noyer of the cliffs opposite the town of Waterford, in which the Old Red Sandstone may be seen forming slightly inclined beds that cap the hills, and rest upon the edges of highly-inclined beds of blue slate belonging to the Lower (or Cambro) Silurian period.

The Carboniferous Limestone of the south of Ireland is always conformable to the Old Red Sandstone below, although it often overlaps it, in consequence of the comparatively small area within which the Old Red Sandstone was deposited, the Carboniferous Limestone being much more widely extended. In one place, near Taghmon, County Wexford, a patch of the Carboniferous Limestone rests directly on the Cambrian rocks, at a distance of nine miles from the remainder of the Carboniferous Limestone, showing that the Cambrian had there been denuded of the whole of its former covering of Lower Silurian, and that the Carboniferous Limestone, spreading beyond the limits of the Old Red Sandstone, came to lie directly on the Cambrian. A similar occurrence is known at Hafodty, near Corwen, in North Wales, where an isolated patch of Carboniferous Limestone rests on the lower part of the Upper Silurian rocks, at a distance of ten miles from the main mass of the Carboniferous Limestone, which now ends in an abrupt escarpment, 600 feet in height, just north of Llangollen. These two cases are proofs also of the subsequent denudation or removal of the Carboniferous Limestone itself, since we must believe that the now separated portions formed originally parts of a continuous mass of limestone that covered the whole surrounding country.*

In the south of Ireland we may follow the boundary of the Carboniferous Limestone and Old Red Sandstone through the counties of Kilkenny and Carlow, so as to find the most convincing proof of the denudation of the Lower Silurian rocks, even to the extent of laying bare the granite which lay beneath them, before the deposition of the Old Red Sandstone, and of the subsequent overlap of the Carboniferous Limestone, and its deposition on the bare granite without the intervention of any other formation.† Fig. 91 is a diagrammatic section taken across

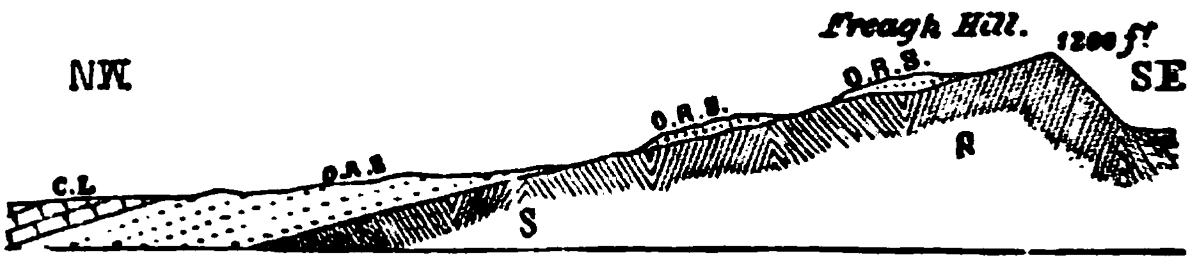

Fig. 91.

Section from N.W. to S.E. over Freagh Hill, 1200 feet high.
S. Lower Silurian.
O. R. S. Old Red Sandstone.
C. L. Carboniferous Limestone.

Freagh Hill, a few miles north of Thomastown, in the county of Kilkenny. The Lower Silurian rocks, marked S S, were tilted and contorted, and a level surface formed by denudation across their edges, on which the Old Red Sandstone was deposited unconformably, with the Carboniferous Limestone conformably upon it. Subsequent denudation has removed the Carboniferous Limestone from all the high ground, and also the Old Red Sandstone, except one or two patches of it.

* See Sheets 74 N.W. and 74 N.E. of the Geological Maps of England and Wales, and Sheet 169 of Ireland.

† It is necessary, in order to explain fully the subject we are describing, to take for granted that the student knows what the Carboniferous Limestone and Old Red Sandstone are. He may either refer to their description as given further on, or return to this chapter at a future period.

This more recent denudation has re-exposed in places the old surface of Lower Silurian rocks on which the Old Red Sandstone was deposited, but it has even gone beyond that, for the valley at the south-east end of the section has been excavated in the Lower Silurian rocks by that subsequent denudation. That valley did not exist at the time the Old Red Sandstone was deposited, otherwise it would have been filled with it, and some part, at least, of it would now remain there.

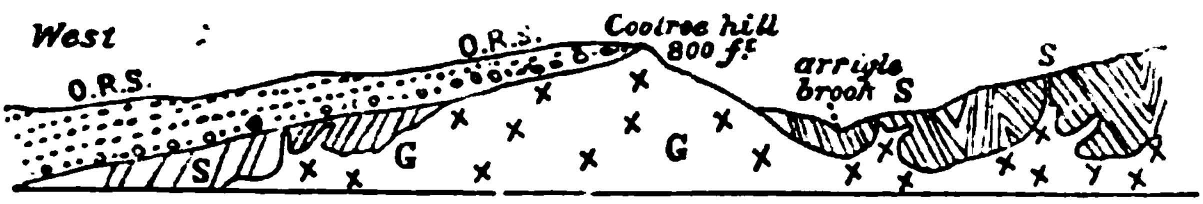

Fig. 92.

Section from west to east through Coolroe hill, and across the Arrigle brook, near Glenpipe.

G. Granite.
S. Lower Silurian.
O. R. S. Old Red Sandstone.

Fig. 92 is a diagrammatic section taken a few miles south of Thomastown, where the denudation that had acted previously to the deposition of the Old Red Sandstone had laid bare a portion of granite. The Lower Silurian rocks are traversed by granite veins in the neighbourhood, and are, near the granite, altered into mica-schist. The Old Red Sandstone, on the other hand, rests upon the granite quite undisturbedly; it is quite unaltered by that rock, and is obviously made chiefly of granite sand, containing occasionally even granite pebbles, though not so many of those as fragments of the slate rocks, when it rests upon them. The granite is now readily decomposed and easily crumbles into sand, and did so apparently quite as easily at the time the Old Red Sandstone was deposited upon it.

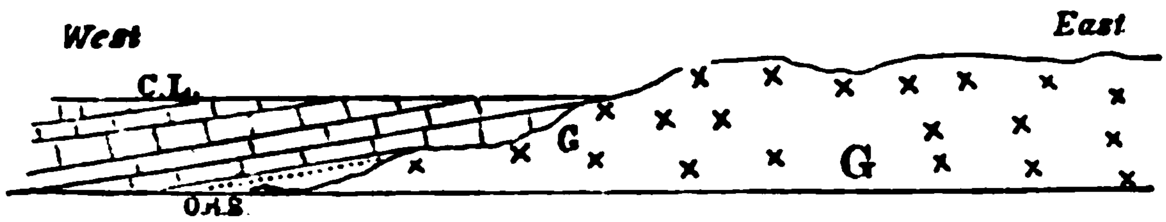

Fig. 93.

Section from west to east in County Carlow.

G. Granite.
O. R. S. Old Red Sandstone.
C. L. Carboniferous Limestone.

Fig. 93 is a diagrammatic section representing the "lie" of the rocks in County Carlow, about 15 miles north of Thomastown, where Granite and Carboniferous Limestone lie side by side, making low gently undulating ground, largely covered with limestone gravel, which has been omitted in the diagram. The limestone dips gently from the granite, but is quite unaltered by it, is not traversed by any veins from it, and was evidently deposited in the sea upon a bare floor of granite, just in the same way that beds might now be deposited upon the bare granite if it were again depressed beneath the sea. No Old Red Sandstone appears here from beneath the Carboniferous Limestone, as it gradually thins out and disappears as we proceed north from Thomastown. As, however, it does appear again a few miles to the westward, some has been introduced into the diagram to suggest the probable mode of its occurrence in that direction.

Unconformability involves the Denudation and Submergence of Dry Land.—From what has now been said it appears certain that denudation implies the necessity of rock being lifted into dry land,

while the deposition of an unconformable set of beds upon their new surface proves their subsequent depression. It follows that there must have been a considerable geological interval between the periods of formation of sets of unconformable beds, and that we may expect to discover in some other region the beds which were deposited during this interval, and perhaps to find there a regular conformity throughout.

The existence of dry land is often confirmed by some curious independent evidence, as in the case of the granite sand and fragments scattered in the Carboniferous limestone of Dublin, the most probable cause for their occurrence being their transport in the roots of plants, which, growing somewhere on the granite land, were eventually washed down into the Carboniferous Limestone sea.

Such an apparently uninteresting circumstance as the relative lie and position of two sets of rock, thus gives us, when it is properly studied, a curious and unexpected history.

Practical Importance of the Subject.—The practical importance of this subject is only just now beginning to be appreciated. Few persons have any idea of the great sums of money that have been wasted in coal-mining alone from an ignorance of the principles here expounded. Even within my own personal experience I have become aware of the fruitless expenditure of sums, which, if capitalised, would afford an income for ever that would go far to pay the present annual cost of H.M. Geological Survey of the United Kingdom. Within the last year or two I have heard of costly shafts being sunk in places where, if they ever pierce the Triassic and Permian rocks, they will find the Coal-measures have already been removed, and will come down to some formation that lies below the Coal-measures.

On the occasion of the meeting of the British Association in Birmingham, in the year 1865, I gave an evening lecture on this subject, in which I entered especially on the examination of the probable position and extent of the coalfields that lie buried beneath the New Red Sandstone, and Permian districts of the British Islands. I took the sections which have been published by the Geological Survey, and connected those of North Staffordshire and Derbyshire with those that cross Flintshire and Derbyshire, Shropshire, South Staffordshire, and Leicestershire, and then inserted several hypothetical cases for the position of the Coal-measures, and the lower palæozoic rocks beneath the horizontal cover of the Permian and Triassic rocks. The result was strongly in favour of the hypothesis which supposes that the Coal-measures occur beneath those formations in the same way that they do where they are not covered by them; not, that is to say, in great continuous sheets, but in isolated coalfields, separated by spaces in which lower rocks rise up to the base of the superincumbent formations. Any one of sufficient knowledge and experience, who studies any good geological map of the British Islands, must, I think, arrive at this conclusion, that the surface formed on the palæozoic rocks is of high geological antiquity, and that the part of it which is covered by newer formations does not essentially differ in character from that which is not so covered.

It seems a perfectly legitimate conclusion that the relations of unconformability between the older and newer rocks, which we can prove to be true in so many places throughout England where we can see them, probably occur in many other places where we cannot even guess at them. I have hitherto hesitated to pronounce a very decided opinion on these points, out of deference to what appeared to be the hesitation of my seniors; but as I am beginning to be entitled to assume the character of a

senior myself, I no longer hesitate to avow my belief in the great geological antiquity of the general surface of the Palæozoic rocks, and so far to anticipate the Report of the Royal Coal Commission as to declare the opinion announced at the lecture in Birmingham, that any shaft sunk through the New Red Sandstone, at a distance from our present coalfields, has *only a chance* of hitting a subterranean coalfield, and is at least as likely, and in some places much more likely, to come down on an old eroded surface of some formation that lies below the Coal-measures. Doubtless many good workable coalfields exist beneath the plain of New Red Sandstone, but the total unconformability between that formation and all those that lie below it deprives us of all clew as to the position of these coalfields. The depth at which these may be found, that is to say, the total thickness of the overlying New Red Sandstone and Permian formations which may have to be pierced before the *chance* of reaching Coal-measures can be attained, is put, by my colleague Professor Ramsay, at about 5000 feet. In this I quite agree with him, having long ago assigned a minimum thickness of 3000 feet as that to be expected to lie above any workable coals in the districts between the coalfields of the Midland Counties.*

Overlap is another consequence of the elevation of rock into dry land and its subsequent depression beneath the sea. It has both a scientific and practical importance, which has hardly yet been sufficiently appreciated. When thoroughly understood and applied, it will, perhaps, explain many geological problems which are now obscure, and correct many yet unsuspected mistakes.

Overlap occurs in a perfectly conformable series of beds when the upper beds extend or extended over a wider space than the lower, either in one direction or on all sides. It is obviously the result of the gradual sinking of an old land, and the gradual spread of the sea over its sloping shores and undulating surface, so that the sea area is being continually, but slowly extended, and the beds formed in that sea correspondingly expanded. The whole upper series will be conformable in itself, but, as a series, it will rest unconformably on the rocks below.

When, however, a mass of beds so formed comes itself to be dislocated and eroded, the appearances presented by the rocks as they are ultimately left may easily be such as to lead the observer to conclude that there is unconformability among the beds of the upper series. This mistake may have two origins. In the first place, when the beds of the upper set, which rest directly on the lower rocks in one place, are not the same beds which rest upon them in another, it may be hastily concluded that this is due to unconformability among the beds of the upper set instead of to overlap. In the second place, this gradual depression of an old land may cause great changes in the lithological characters of beds which are really contemporaneous, and equal similarity in beds deposited under similar conditions at very different periods. The observer, then, who examines isolated exposures of such beds may be readily induced to consider beds to be contemporaneous which belong to very different parts of a geological period, or assign

* *South Staff. Coalfield: Memoir*, p. 200.

different parts of a period to beds which were really formed contemporaneously, or nearly so.

Suppose, for instance, that when the old land began to sink beneath the sea, gravels and coarse sand were formed upon its coasts, ultimately compacted into conglomerates and sandstones. As the depression continued and the coast receded, and the water over these beds deepened, gravel and sand might no longer be deposited there, but fine mud perhaps, or possibly hosts of marine animals might grow and live there, and limestone be formed. A great thickness of such deposits might eventually be accumulated over these sandstones and conglomerates which were formed originally close to a beach. But during all this period of depression, the land, although sinking, might not be all sunk ; the coasts would have receded, but sands and gravels might still be forming on the new shores identical in character with those produced on the old ones. These sandstones and conglomerates, however, although precisely like the first, and ultimately covered perhaps like them with precisely similar shales and limestones, would yet not be the same beds as the first, or contemporaneous with them. The first formed beds would lie at the bottom of the whole series, but the last formed beds—those produced on the last bit of coast remaining perhaps—might be near the top of the series. Nevertheless, when this series of beds came itself to be elevated into land, tilted, contorted, fractured, and denuded, and distant portions of it only left for our examination, geologists who were not on their guard might easily suppose a succession of sandstones, shales, and limestones, of precisely the same characters, occurring always in the same order, and certainly belonging to the same formation, to be separate parts of the same identical beds.

Such a mistake, perhaps, would never be corrected until the whole country came to be examined, not only in a detailed, but an exhaustive manner, by the help of maps on a sufficiently large scale to enable the geologist to mark on them the actual facts, and not merely his deductions from those facts.*

In this chapter much has unavoidably been alluded to which the reader has not yet had explained to him. The questions of unconformability and overlap are so intimately linked with that of denudation, that they require to be studied together. It is from unconformability that we derive some of our most vivid notions of what may be effected in the process of denudation. The various geological agencies concerned in that process will come before us in the next section, and we shall again have to refer to the subjects discussed in the present chapter, and to give illustrations of the great geological problems involved in unconformability, overlap, and denudation.

* The six-inch maps, employed from the first by the Geological Survey in Ireland and Scotland, allowed of this being done, and such maps are now supplied for the north of England. The survey of Wales and the southern part of England had to be undertaken without this advantage, and its authority must be proportionately inferior. I hope my colleagues will pardon this expression when I say that I am even painfully conscious of its application to my own work. Hard as we worked in North Wales, minutely as I endeavoured to gather details of facts in the South Staffordshire coalfield, one's memory and one's note-book, aided as they were by the one-inch map, without which we could have done nothing, are yet but a poor substitute for the sheets of the six-inch map on which the actual data can be depicted precisely as they were observed, unobscured by any suggested lines of boundary or hastily drawn inferences, which as often hindered as they helped the true result being arrived at. The geological survey of Wales and the south of England must be recommenced when the six-inch Ordnance maps of those countries come to be published.

CHAPTER XII.

THE GRANITIC OR HYPOGENOUS ROCKS VIEWED AS ROCK-MASSES.

In the previous chapters we have examined chiefly the petrological relations of the Aqueous Rocks: we have now to examine those of the Igneous class. The different kinds of igneous rocks have been described under the head of Lithology, and it was shown that these differences partly depended on the difference of their chemical composition, and partly on the difference of structure and texture resulting from the physical circumstances—as pressure and rate of cooling—under which their consolidation took place. The Granitic rocks cooled slowly, and under great pressure, at some considerable depth in the interior of the crust of the globe. The Volcanic rocks, on the other hand, were consolidated at the surface, while the intermediate and variable class, which we have called Trappean, have been solidified sometimes at the surface and sometimes at a greater or less depth beneath it.

In the present chapter we shall consider how the granitic series occurs in rock-masses, and forms in this way an important constituent of the earth's crust. In the succeeding chapter we shall treat of the trap-rocks. The volcanic series, in accordance with the plan hitherto pursued in this work, will be discussed in the next part, under the head of Geological Agencies.

Fundamental or Primeval Granite.—The idea which formerly prevailed among geologists was, that the granite, which now appears at the surface, is part of a primitive or primeval rock, forming a fundamental mass at the base of all other formations. Werner held that it was the first rock crystallised from an original menstruum, and that it was followed by a crystalline precipitation first of gneiss and then of mica-schist. When, however, the igneous origin of granite came to be recognised, as proved by Hutton and his followers, the idea was modified into that of granite being the rock first formed on the cooling of the external coat of the molten globe. The ghosts of these ideas still linger among us.

If we admit the idea of our earth having been originally a molten globe as a probable one, it seems hardly possible to suppose that the rock first formed on its cooling surface would be one like granite. Even if it contained precisely the constituents of granite, it would seem more

likely, on the first cooling of its surface, to form scoriaceous trachyte, obsidian, or pumice. There is no instance known, so far as the author is aware, of any igneous rock which can be shown to have been consolidated at or near the surface forming such a solidly crystalline mass as granite. Even the porphyritic trachyte, which most resembles it, has always been denuded of a very considerable cover, as in the case of the Mont Dor, and can always be distinguished from granite by the form of its crystals and the pores and quasi scoriaceous cavities which are dispersed through it.

We may take it for granted, then, that all true granite, whether it be formed by the cooling of an independent igneous mass, or by that of a mass molten *in situ*, was consolidated at a great depth beneath the surface, and therefore very slowly and under great pressure. That large areas of such deeply-formed masses now appear at the surface can be no difficulty to us after what we have seen of the action of denudation in the last chapter. There is, however, this much truth in the fundamental character of granite, that we know of no great mass of any kind of rock appearing from underneath any considerable mass of granite.* We have no reason to suppose that if we began to bore in any such mass we should ever pierce another kind of rock, even if it were possible to continue our operations till we came down to yet molten rock, which, as far as we can guess, would most likely be still unconsolidated granite. Still it does not follow from this that the rocks which we find anywhere resting upon any mass of granite are the lowest or oldest of rocks, or that they pass under all other rocks except the granite. In many cases where true granite appears at the surface it can be shown to have come *through* a great thickness of stratified rocks which must therefore have been in existence before it, or are older than the consolidation of the granite. It can also be shown that different masses of granite were brought into the place they now occupy, and consolidated at very different geological periods. They not only penetrate very different formations, but the granite which penetrates one formation was not only consolidated but denuded before the deposition of another formation, which is itself in other places penetrated by granite.†

Position and Form of Granite.—The position and mode of occurrence usually assigned to granite by the older geologists was something

* The only fact that could be taken as an indication of such an occurrence is the appearance of veins and dykes of greenstone traversing granite, as in the country near Newry.

† The different theories in the formation of granite are discussed by Dr. Haughton in Appendix B to the 1st Lecture of his Manual. He well says:—"The evidence of the geologists has been collected in the field, and though it is wanting in the scientific precision which the chemists have called to their aid, yet it possesses a force which all the arguments on the other side have as yet failed to oppose."

like that in the following diagram. It was taken for granted that this

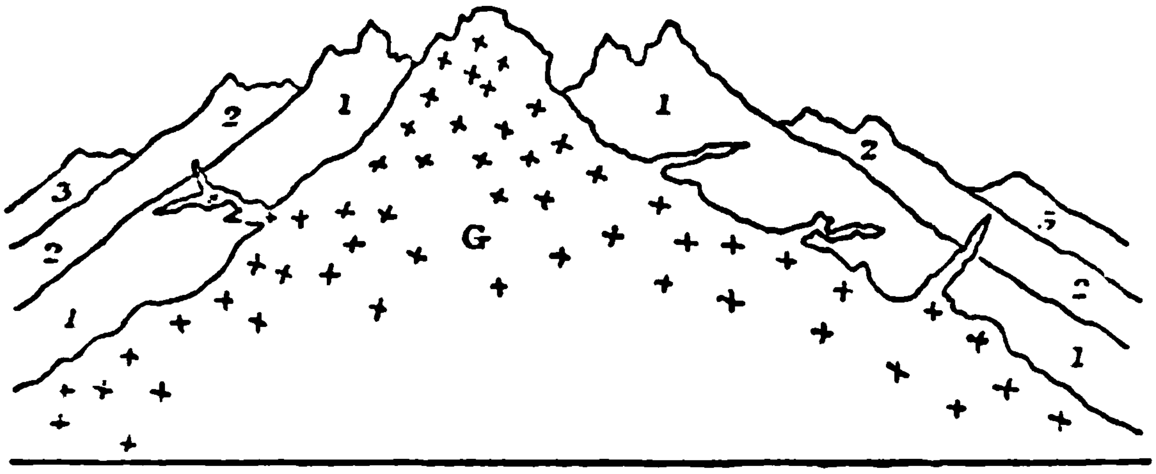

Fig. 94.
Supposed position of granite.

G is a mass of Granite forming the axis of a range, and 1, 2, 3 are the stratified rocks dipping from it in each direction, the lowest or oldest, No. 1, being next to the granite, and the highest or newest, No. 3, the farthest from it.

rock acted as the motive power in elevating and tilting other rocks, and formed the axis of mountain chains, with the lowest formation resting against it on each side, and a regular upward succession as we proceeded from it. The occasional appearance of granite masses in the centre of mountain chains, where not only the uptilting action had been greatest, but the denudation also, favoured this view. It seemed to be further confirmed by the fact that gneissose rocks often occurred next the granite, and that the metamorphism of the rocks faded away as they receded from the granite, it being assumed that gneiss was older than mica-schist, and mica-schist than clay-slate. These assumptions obviously saved the labour of the minute observation of the differences between stratification, cleavage, and foliation, in remote and difficult districts. Neither would any labour have given adequate results without sufficiently large and accurate maps on which to record the observations as they were made.*

There seems to be little doubt that although granite may in certain instances assume the position suggested in Fig. 94, it is by no means a necessary mode of occurrence, nor, as a matter of fact, does it often occur. We can hardly take better examples of the mode of occurrence of true granite than those of Leinster in Ireland, and those of Devon and Cornwall in England.

Leinster Granite.—The granitic district in the south-east of Ireland, extending from Dublin Bay to near New Ross in County Wexford, is the largest surface exposure of granite in the British Islands, being 70 miles long and from 7 to

* We are in fact only just now beginning to feel our way to true conclusions in this part of geology, and even with the staff and the maps of H.M. Geological Survey I can only look forward to the completion of such a preliminary statement and delineation of facts as shall lay down a fair basis for the investigations of our successors in the next generation.—See the note at foot of p. 238.

17 miles wide. There were in this district at least two great geological formations, each consisting of shales or slates and sandstones, and each several thousand feet thick, at the time of the intrusion of this granite. These two formations are known as the Cambrian, which is the lowest or oldest, and the Lower or Cambro-Silurian, which rests in some places unconformably upon the Cambrian. Now in no instance is any part of the lowest or Cambrian formation found reposing on or coming against the granite, though it comes to the surface in some places within two or three miles of the granite, as shown in the section (Fig. 95). The Lower

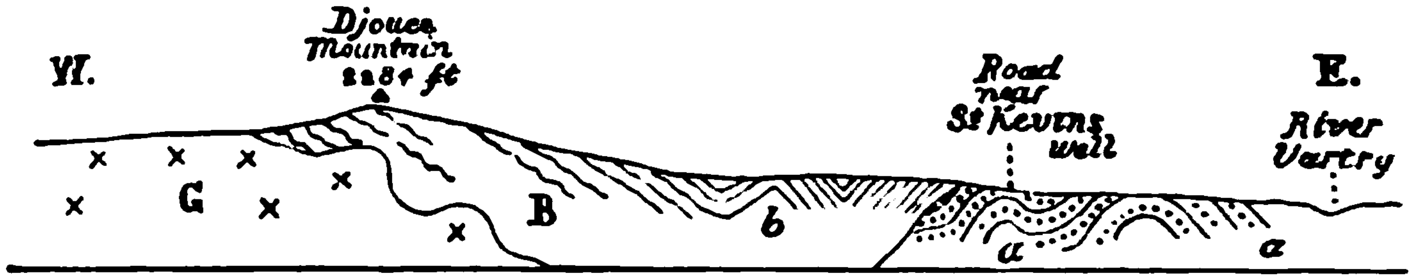

Fig. 95.

Section across Douce Mountain, County Wicklow.

a. Cambrian. B. Silurian altered into mica-schist.
b. Silurian. G. Granite.

Silurian rocks, however, have been broken into by the granite, and penetrated by granite veins, and we are compelled to suppose, therefore, that the granite must have *passed through* the Cambrian rock below. The direction of the length of the granite exposure is about N.E. by N., while that of the strike of the adjacent slates is more nearly N.E., or even E.N.E., which is the mean strike of their cleavage. It is remarkable that, although the slates immediately on the flanks of the granite ridge often dip from it at low angles, the dip generally increases rapidly as we recede from the granite, the slates sometimes becoming vertical, or even dipping towards the granite, as indicated in Fig. 95.

It is very difficult to come to any decided conclusion as to the connection between the intrusion of the granite and the disturbed position of the adjacent rocks. It is clear that the granite did not exercise any general elevatory action on the rocks about it, or the granite area would now be surrounded by concentric belts of rock, the lowest of which would be next the granite, and the others newer or higher as we receded from it. The granite seems, as it were, to have eaten its way upwards through whatever lay above it, penetrating it slowly and gradually in a very irregular manner, sending numerous and variously reticulated veins into it of very various dimensions and extent, and probably absorbing much of the rocks above it into its own mass as it rose. That these masses had been disturbed and tilted before the intrusion of the granite seems to be indicated by the way in which large masses of them dip down into the granite and end suddenly against its irregular surface. Though it is of course possible that this tilting of the beds accompanied the intrusion of the granite, my own observations have produced the other impression on my mind.

It is certainly true that the masses of mica-schist on the flanks of the granite range generally dip from its centre on each side. Dr. Oldham's sections across Lugnaquilla, however, show the mica-schist there to be horizontal towards the summit of the hill, which is about the centre of the granite ridge, and to be, as it were, interstratified with horizontal vein-like belts of granite; while on the flanks of the ridge the mica-slates dip at a high angle from the central ridge, and are a good deal contorted, but the beds terminate downwards against a general irregular surface of granite. In these delineations of the relations of the rocks I have no doubt of the correctness of my distinguished predecessor's ideas. In some places, at a distance of a mile or so from the granite exposure, the slate becomes

vertical, or dips at a high angle towards the granite exposure. On the eastern flank of the granite hills the dip of the mica-schist or clay-slate seems to be generally less than on the western, and the subterranean surface of the granite appears not to descend so rapidly into the earth on the eastern as it does on the western flank, since small bosses of granite are exposed at intervals among the slates at the present surface of the ground between the main granite chain and the sea-coast.

It seems to my mind almost certain that the whole of Wicklow and Wexford is underlaid by a continuous mass of granite with a very irregular surface, and that the form of the granite surface has little or no connection with the position of the beds above either in dip or strike. Neither has the intrusion of the granite had any direct connection with the occurrence of the trappean rocks, either felstones or greenstones. Those traps, whether they are contemporaneous or intrusive—that is, whether they were erupted to the surface during the deposition of the slates, or thrust in among them afterwards—were all in the slates before the intrusion of the granite. Not so with the "Elvans" (veins of quartzose porphyry), however, and other granitic veins, many of which certainly are of an origin contemporaneous with, or subsequent to, the granite.

The wide spread of the granite area beneath the variously tilted and contorted cover of the slate rocks is also rendered probable by the narrowing of the exposure of the granite where the present surface rises into mountains, and its comparative width in the lower grounds. In the low ground in the northern part of County Carlow, to the northward of Tullow, the granite area is 17 miles wide, and its central portions are entirely free from belts or patches of mica-schist. As the ground rises on the northward, however, into Lugnaquilla (3040 feet), or on the southward into Mount Leinster (2610), the width of the surface of exposure of granite is contracted to 5 or 6 miles, and the higher grounds are patched with bands and roundish spaces of mica-schist. Had a cover of an additional thousand feet or so been left over those hills, the granite would have been altogether concealed by the mica-schist. The width of the low granite area, on the other hand, is due to the removal of some 2000 feet of cover which formerly connected the hills of Lugnaquilla with those of Mount Leinster. These ideas as to the mode of occurrence of the Wicklow granites may be illustrated in a rough and general way by the following diagram :—

Fig. 96.

Ideal section representing the relations between G, a granite mass, and S, a superincumbent mass of slate-rock, the zigzag lines being intended to mark the part metamorphosed into mica-schist, the lines *a b*, and *c d*, etc., representing different surfaces formed by denudation.

It is here supposed that the mass of slate-rock marked S S was penetrated by the granite mass marked G G. The contortions in the slate-rocks were probably of previous date, but if their production accompanied the intrusion of the granite there was no necessary correspondence between the outline of the granite surface and the dip of the slates. The zigzag lines are intended to represent the extent to which metamorphism affected the slates, and died away as it receded from the granite.

The horizontal lines *a b*, *c d*, *e f*, represent the different surfaces produced on the rocks by denudation. These would of course never be really horizontal, but would undulate in various directions. As the figure, however, is only a diagram, and as the true form of these surfaces would vary indefinitely and continuously, we may as well suppose them to have been horizontal as imagine any other forms for them. So long as the surface was represented by *a b*, there would be no appearance of granite. There would, however, be an indication of its existence below, as in one part some of the metamorphosed rock reaches that surface. When the surface was worn down to *c d*, the exposed metamorphic area would be wider, and a granite vein would appear here and there. These would be still more numerous and larger on the surface *e f*, while that represented by *g h*, would expose some width of the granite mass; this would be wider when the surface *i j* was exposed, and grow still wider on those represented by the lines *k l*, and *m n*. Now the surface represented by *g h* would show precisely the state of things represented in Dr. Oldham's sections across Lugnaquilla, while the surfaces *i j*, or *k l*, would represent the section across the low lands of County Carlow, where the valley of the Slaney crosses the granite area. This explanation of the facts shown by the Leinster granite must be obvious to any one who walks through the country with the maps and sections of the Geological Survey in his hand. It explains also the fact, that a partially metamorphosed area occurs here and there occasionally in the lower slate country, without any exposure of granite, though a subterranean boss of it doubtless rises towards the surface at that place. It also explains the variations in the width of the metamorphosed belt that surrounds the granite of the main chain, and that of the outlying bosses; that variation in width depends on the various inclination of the granite surface below. Where the granite sinks slowly the metamorphic band is wide, where it goes down at a rapid slope the surface outcrop of the metamorphic belt is narrowed accordingly.

Granite of Devon and Cornwall.—Although I have not seen much of these granites, yet the little which I have seen, taken together with the study of published maps and descriptions, especially those of Sir H. de la Beche,* convinces me that the same general reasoning applies to them as to those of Leinster. The granitic exposures of Dartmoor, and the other masses which rise to the present surface in Devon and Cornwall, are merely the irregular knobs of a connected mass below. The slates dip on to and end against this mass, the irregular form of whose surface has very little connection with the position of the beds of the country. Those beds may be "dog-eared," as it were, for half-a-mile or so on the immediate flanks of the granite bosses, and metamorphosed here and there, of course to a greater or less extent according to circumstances. The general strike of the rocks, however, in the district between the granite bosses, is not affected by their occurrence. The granite bosses are not surrounded by concentric belts of rock, the lowest the nearest to the granite, and so on. The granite penetrates the Coal-measures, and behaves to them precisely in the same way as it does to the Devonian slates; and the relations of the older igneous rocks in the Devonian slates to the newer granite, and of the still newer Elvans to both, seem to be precisely similar to those of the corresponding rocks in Leinster.

Nevertheless, it can easily be shown that the time of the intrusion of the granites of Cornwall and Devon is much more modern than that of the granite of Leinster. The formations called Old Red Sandstone and Carboniferous Limestone were deposited on the bared surface of the Leinster granite, and contain fragments

* It is perhaps advisable to mention that the maps of the West of England, published as those of the Geological Survey, were not executed by the Survey, as at present constituted. Sir H. T. de la Beche chiefly executed them himself, with the assistance of friends, working *en amateur*, at his own cost. They were engraved and coloured at the expense of the public, and made the basis of the Government Survey which is now going on.

of it; while the granites of Devon and Cornwall penetrate the formation called the Coal-measures, which is more modern than the Carboniferous limestone.

The entire want of conformity between the irregular outline of the surface of the granite and the position of the aqueous and metamorphic slates about it has, I believe, been the origin of much scientific and some practical misapprehension. Mr. Curwen Salmon was kind enough to send me some time ago an instance of the latter from one of the Cornish mines, where, trusting to the apparent dip of the slates, a shaft was sunk, which was expected to be wholly in the slate, but which unexpectedly came down on a subterranean mound of granite. The student will do well to recollect that it is quite possible for beds to dip directly at and into a mass of granite.

Granites of Ulster.—From the descriptions of Dr. Haughton and others, it appears that the green siliceous Silurian slates that come in contact with the Ulster granites are not at all metamorphosed by them. Their purely siliceous character probably renders them unalterable by mere heat. Where, however, the granites penetrate the Carboniferous limestone, it appears that they are converted into a greenstone (or syenite, according to the German nomenclature adopted by Dr. Haughton), containing anorthite (a lime felspar) and hornblende.

Granite of the Pyrenees.—A recent visit to Cauterets in the Pyrenees showed me that the mass of granite there was intrusive, with only one felspar. The rock cuts through and sends short veins into the black slaty rocks about it; but when those are very arenaceous scarcely alters them at all. Near Cauterets the presence of the granite would not even be suspected if the examination of the slate-rocks were arrested at ten yards before coming to the granite, while the instant the granite is reached it has exactly the character which it retains for some miles, both on the summits of the hills and in the bottoms of the deepest valleys and ravines.

Granite more likely to be associated with Older than Newer Rocks, from its source being in interior of Earth.—It is doubtless true that granite is found more frequently associated with the older rocks than with the newer; in other words, with the lower rather than the higher rocks. The reason of this, however, is clearly that the very source of granite is in the interior of the earth. Granite, in order to reach the higher, must pass through whatever lower rocks there may be in the way. Many injections of granite may have proceeded a certain distance from the interior, penetrating only the lower rocks; but none can have reached the upper without traversing those below them. That granite should be most frequently associated with the lowest rocks follows, too, from the very nature of granite. We can hardly imagine that molten rock, which reached or came near to the surface, would, on consolidating, form granite, but rather some other kind of igneous rock—a felstone trap, or a trachytic lava, as the case might be.

Another reason why granite is found principally in connection with rocks that have formerly been deep-seated might be adduced, and that is, that all granite now found at the surface ought, if the views here advocated are correct, to be there in consequence of vast denudation having taken place. This denudation would expose the lower rock to view, while the parts of the higher rocks that were perhaps equally penetrated by the granite would be removed; the other parts which remain being now at a distance from the granite, and showing no signs

of such penetration. It is where the lowest or oldest rocks come up to the surface that we should expect most frequently to meet with granite, and this we find to be the case.

Metamorphic Granite.—An idea seems to have sprung up in the minds of some geologists that all granite is of metamorphic rather than of original igneous origin. Though unable to entertain such a notion with regard to the granitic masses of Leinster, and still less of Ulster, in Ireland, or Devon and Cornwall in England, and other places, where the granite occurs in large independent masses, surrounded by a mere film of metamorphic schists, or, as in Ulster, by none at all, I am by no means inclined to deny that there are, in highly metamorphosed districts, masses of rock, to which it would be difficult to give any other name than that of granite, which are nevertheless of wholly metamorphic origin. If we trace back all sands and clays to their origin, we are compelled at last to derive them from the waste of some igneous rock. Some of them, at all events, must be derived originally from the waste of some granite or granitic rock. If not, from what other source are we to seek for them? Before any sandstone or clay could exist on the globe, there must have been some *primitive* rocks containing quartz and felspar, and apparently mica, for the very oldest unaltered rocks contain micaceous spangles,—worn chips of some original crystals of mica. This, it will be observed, is a very different thing from saying that any granite now visible to us is part of that *primitive* rock. It is quite conceivable that all those primitive rocks may have been destroyed or altered long ago, and that, therefore, they not only cannot be found, but do not exist.

But if any masses of sandstone and clay derived from the waste of a granite rock retain their original constituents in the proper proportions, and are afterwards brought under such conditions as would induce them to crystallise again into felspar, mica, and quartz, they would be brought back into the form of granite. If this occurred at any great depth, and the materials passed through a state at all approaching fusion, masses and veins of that re-fused granitic material might easily be injected among the surrounding rocks, and all the local phenomena attending the intrusion of originally formed granite might be imitated.

Whenever, therefore, granite occurs in a widely and highly metamorphosed district, I should be quite ready to treat it with great suspicion, and look upon it as possibly a metamorphic rock. Such suspicion naturally arises when we find the granitic character extending outwards into the metamorphosed rocks, or in other words, when we trace a gradual increase of metamorphism as we approach the granite, and at last pass without violent transition into that rock. Yet, even in a regular intrusive granite, a kind of reaction of the different substances it meets with may be distinctly traceable for a certain distance into the

mass of the granite itself. Dr. Boase, for instance,* in speaking of their mutual influence on each other, says that when the granite is schorlaceous, the slate adjacent to it is also combined with schorl.

Nevertheless, while such interblending of mineral characters takes place between granite and its surrounding strata in cases where the granite is held to be of igneous origin, there are instances where it occurs on such a wide scale, and where the gradation from unaltered rocks into granite is so gradual, that we can hardly escape the conviction that this granite really represents a mass of strata in a state of complete metamorphism. An excellent illustration of this feature occurs in County Galway. The recent work of the Geological Survey in that region, carried on by Mr. G. H. Kinahan and his junior colleagues, has shown that two kinds of granite are largely developed there. Of these, one is of intrusive character, sending veins into the adjacent rocks, and containing one kind of felspar only (viz. orthoclase), while the other contains two felspars (oligoclase as well as orthoclase), the orthoclase often occurring in large pink crystals, giving a porphyritic character to the rock. Where the junction of this porphyritic granite with the metamorphic rocks can be clearly seen, it is often to be observed that the granite passes insensibly into the surrounding gneiss. This is caused by the flakes of mica assuming gradually a parallelism in the rock, giving it more and more a foliated character, till it is difficult to say where it passes from granite to gneiss. With true intrusive granite there is never any such difficulty. Hand specimens even can often be got with the granite and gneiss, or other metamorphic rock, as definitely bounded as can be imagined.†

* *Trans. Roy. Geol. Soc. Cornwall*, vol. iv. p. 457.

† One of the earliest writers (if not himself the first) to make detailed observations on large granitic areas, and the relation to them of the dip and strike of the surrounding stratified rocks, was Mr. Hay Cunningham, an observer too soon lost to science, and whose writings, from the limited circulation of the journals in which they chiefly appeared, are less known than they deserve to be. His "Memoir on the Geology of Kirkcudbright," published as a prize-essay in the *Transactions of the Highland Society*, vol. xiv., is well worthy of being read by every geologist who takes an interest in the questions that relate to the origin of granite, and the connection of granite with metamorphism. He pointed out very clearly, at a time when the value of the observation could not be understood, that the granite of Galloway has not been thrust up through the surrounding Silurian rocks, which in that case would have been found to dip away from the granite; that, on the contrary, the greywacke and shales were found to re-appear on the farther side of the granite, and with the same strike as before; that, in fact, the granite occupied the place of so much stratified rock. Though his essay is full of sagacious inference, he did not live to see the full application of his observations. The now well-ascertained fact that over wide areas granite has actually been substituted for stratified rock, and that without the mere disruption or displacement of the latter, is fatal to the early notion that granite was erupted in huge molten masses through the crust of the earth, and was then a chief agent in the upheaval of mountain chains. Whether we are to regard granite as a rock connected with a vast highly heated granitic "magma" within the crust of the earth, and slowly eating its way upward by absorbing the overlying rocks, as suggested by the author in a previous page, whether we ought to look on granite as in all cases a truly metamorphic rock, or whether we may meet

Granite Veins.*—Granite veins sometimes differ sensibly in lithological character from the parent mass from which they proceed. They sometimes contain larger and more perfect crystals of the constituent minerals than are seen in the mass of the rock, and at others become more fine-grained, and close in texture, appearing to lose their quartz, or their mica, or both. The more largely crystalline veins are generally those which occur in the granite itself, and these are not probably intrusive veins, but veins of segregation, or even of subsequent infiltration.

The veins which proceed from the granite into the surrounding rock must clearly be intrusive veins, and they can frequently be shown to

Fig. 97.
Granite veins traversing Lower Silurian slate (there altered into mica-schist), on the shore beneath Killiney Hill, County Dublin. The larger masses of granite are marked G.

have been intruded at different periods. This is seen in the accompanying sketch (drawn by the late Mr. Du Noyer) of a locality, readily

with granite formed in both ways, are among the moot-points of geology. The student will find some farther discussion of this subject in the section of this Manual treating of Metamorphism.—A. G.

* Granite veins were first carefully studied in this country by the illustrious Hutton, and were used by him as demonstrative evidence of the former molten condition of granite. When he made his famous observation of the granite veins of Glen Tilt, his attendant supposed, from the exuberant delight of the philosopher, that he must at the least have discovered a gold-mine. See *Trans. Roy. Soc. Edin.*, vol. iii. p. 79, also Playfair's Life of Hutton, *Works*, vol. iv. p. 75. The student who would enjoy a masterly description of granite veins should read the Memoir of Playfair and Lord Webb Seymour. *Trans. Roy. Soc. Edin.*, vol. vii.—A. G.

accessible at low water from the Killiney Station of the Dublin, Kingstown, and Bray Railway, where one large, nearly horizontal, vein of granite may be seen to be itself traversed by another vertical one, which terminates upwards in branches and strings. The dark Lower Silurian slate-rocks are altered into glittering mica-schist, except the little bands of fine-grained grey siliceous gritstone, which are interstratified with the clay-slates, and are unchanged. Some of the layers of mica-schist have their surfaces covered with beautiful stellated forms of staurolite, which has been developed in those layers which had the requisite constituents to form the mineral, while they are absent from the intermediate layers. These schistose rocks are entirely surrounded by the granite, and rest in hollows of it, although, as may be seen in the sketch, their beds dip down on to it.

In some cases these intrusive veins appear to cut through the granite itself, being traceable in it by a difference of texture and distinct bounding walls. In other cases, however, it appears to have been merely part of the external portion of the granite which was injected into the surrounding rock. The subsequently formed veins which cut across these, however, could hardly have had the same origin. These, and the very distinct veins of "eurite" or compact granite, which are often traceable through coarser granite, and are sometimes themselves traversed by other similar veins, apparently of subsequent date, are probably not of a date long posterior to the intrusion of the main mass of the granite. It is possible that, on the first consolidation of the upper portion of the granite, cracks and fissures might take place, into which injections of the yet molten rock below might be forced. The upper consolidated part of the granite, although no longer fluid from heat, might yet be red-hot, so that the veins injected into it might be soldered, as it were, firmly to the walls of the fissures.

Mr. Carne* says that the granite veins which penetrate the slates in Cornwall are only seen near the junction of the granite and slates, are generally finer grained than the granite, and are more quartzose but less micaceous; that they pass imperceptibly into the granite—the only case he knew where a vein traversed both rocks being at Carn Silver—and that there is no junction of the granite and slates exposed in which the slates are not traversed by granite veins. He states that the slates are generally harder near the veins, and are almost imperceptibly changed from clay-slate into mica-slate; and that in most places where the junction is seen there is no dislocation or disturbance of the rocks. He adds that the granite veins have no regular direction, although often straight and regular in form, decreasing in size as they recede from the granite.

Mr. Henwood† also says, that granite near its junction with slate sends off veins of all sizes, shapes, and directions, which, when large and horizontal, are called beds, and are then often porphyritic in the centre and fine grained at the sides. In most cases they enclose sharply-defined angular masses of slate, and the cleavage planes of these portions of slate almost always coincide with those of the general mass. On the other hand, long and slender masses of slate penetrate into

* *Trans. Roy. Geol. Soc. Corn.* vol. ii.

† In same *Trans.* vol. v. p. 143.

the granite, and contain masses of that rock. For some distance, also, on each side of the junction, there are unconnected patches of either rock. At some mines, "beds" of granite extend into the slate in a nearly horizontal direction for a great many fathoms, but the position of the latter does not seem to have been disturbed.*

Elvans.—The "elvans" of Cornwall are veins of quartziferous porphyry, differing from granite chiefly in the absence of mica. According to Mr. Carne they vary in width from a few feet to fifty fathoms, and sometimes are inclined at low angles, underlying (from the vertical) much more rapidly than the lodes.† He considers them too wide to be called veins, and speaks of them as "elvan-courses." Dr. Boase‡ says, that elvans are often most like granite in the centre, and more like felstone-porphyry at the sides. He afterwards speaks of "eurite-courses" in the granite, and says they are commonly regarded as fine-grained granite, that they appear to be made of crystals of felspar and quartz, too minute to be distinguishable by the eye. Mr. Henwood remarks,§ that the elvans traverse granite and slate alike, their most usual bearing being E. and W. They more often dip to the N. than to the S., at an average angle of 50°, or less than the average inclination of the mineral veins. He adds, that they are more granitic in the granite than in the slate, but still distinctly traceable in the granite; and also that they are usually more coarse-grained at the centre than near the sides, and often show a spheroidal structure, and some enclose pieces of slate. Similar elvans to those of Cornwall are abundant near the granite of Leinster, and probably in the neighbourhood of all other large granitic masses.

Although the elvans differ somewhat mineralogically from granite, they must, I think, be derived from it as granite dykes, since they only occur in districts where granite also occurs, and they are generally more numerous as we approach the granite. In Leinster they are often traceable in nearly straight lines for some miles, although only a few feet in width, several of them running parallel to each other for such a distance, with intervals of two or three hundred yards between them. They often coincide in strike with the slate or other rocks in which they lie, though they generally cut obliquely across the dip of the beds, and sometimes also across their strike. They often alter the rocks in contact with them; not, however, by converting them into mica-schist, but merely producing a greater induration, a more minute joint-fracture, and a brown ferruginous tinge, giving them what might be called a "burnt" aspect. In the Leinster district the rock of these "elvans" is more like that observable in the small outlying bosses of granite which just show themselves through the slate in the country between the granite hills and the sea, than it is to the granite of the "main chain." Their direction is generally N.E. and S.W., or parallel to that of the main chain of the granite.

* *Trans. Geol. Soc. Corn.*, vol. v. p. 148.

† *Op. cit.* vol. i.

‡ *Op. cit.* iv. p. 292.

§ *Op. cit.* vol. v. p. 161.

CHAPTER XIII.

THE TRAP-ROCKS VIEWED AS ROCK-MASSES.*

THE student has already learnt (Chap. V. p. 107) in what sense the word trap is employed in this volume, what rocks are included under the term, and in what respects these rocks differ from each other in mineral composition. It now remains to describe the geological relations of these masses: that is, the various forms under which they enter into the composition of the geological structure of a country. We are to deal with the rocks, not as mineral substances of varying composition, whose differences can be discriminated in hand specimens in a museum, but as great rock-masses, which play an important part in the architecture of the earth's crust. The distinctions which have now to be drawn among them relate to features which must be studied in the field, and many of which cannot be properly understood without some knowledge of modern volcanic action. That knowledge is necessarily presupposed in the following discussion; but the student who wishes to furnish himself with this preliminary requisite will find, perhaps, a sufficiently detailed account of volcanoes in the next Part of this Manual. He will discover, moreover, that in the study of the trap-rocks (which are to so large an extent merely volcanic rocks of ancient date) he acquires an insight into many features of volcanic action, which it is not possible adequately to investigate in any modern volcano.

* It is proper to state that this Chapter has been entirely re-written by the editor. In conformity with the author's classification, the "trap-rocks" are meant to include rocks of volcanic origin, of palæozoic, secondary, or older tertiary date, along with other masses which, though they did not reach the surface, were intruded among the rocks below, and may, in some cases, have been connected with the operation of volcanic forces. The latter help to connect the volcanic with the granitic rocks. It may be open to doubt whether it would not be better to disuse the term "trap" as the name of a distinct class of rocks, on the ground that most of the rocks so called are certainly of volcanic origin, while of the rest some are so closely connected with the unmistakably volcanic ones that they should in all probability be regarded as the subterranean prolongations or representatives of the latter; while others, such as the quartziferous porphyries, diorites, etc., are so related to granitic and metamorphic rocks, that they might perhaps be most fitly taken in connection with these. The editor has not felt at liberty, however, to alter the classification of his friend; and, fortunately, this is of minor consequence in dealing with the geological relations of the rocks in question, seeing that the rocks which might be excluded form but a small proportion of the whole; and that in regard to their mode of occurrence they can be legitimately treated along with the "intrusive" members of the Trappean series.

The student of British geology is peculiarly fortunate in this branch of his inquiries. In that combination of features which renders our islands so remarkable an epitome of the geology of the globe, not the least important item is the development of igneous rocks which we possess. From the massive felspathic lavas and tuffs of the Lower Silurian rocks, up to the great basaltic plateaux of Miocene age, most of the British geological formations contain somewhere evidences of contemporaneous volcanic activity. And these traces, instead of being confined to limited districts, are found often to range for many miles through groups of hills and wide stretches of lowland.

This copious development of igneous rocks cannot but present many facilities for the study of volcanic phenomena, and of those deep-seated processes which in a modern volcano are inaccessible. The investigation may be approached from a number of different sides, resolving itself, in this way, into several distinct lines of research. These igneous masses may be studied stratigraphically with the proofs of their having been successively erupted at the surface during the growth of the various formations among which they occur. Hence, on the one hand, we may obtain much curious insight into the geological history of a district, while, on the other, by taking a broader view of the whole subject, we may to some extent trace the progress of volcanic action over the whole country. Again, the rocks may be examined, irrespective of the formations to which they belong, as repositories of data respecting the phenomena of volcanoes. They may be studied as chemical or mineralogical compounds, and compared or contrasted with the products of modern volcanoes. When, moreover, we reflect how many of these igneous masses must have consolidated on the floor of the sea, and how rare are the opportunities of investigating the progress of an active submarine volcano, we perceive that an attentive study of our own volcanic rocks may even elucidate some of the less observable features of modern volcanic action. Or these igneous masses may be examined with the view of ascertaining how far volcanic activity may influence submarine life. Thus, in some of our geological systems—among the Silurian rocks of Wales, for example, or the carboniferous limestone group of Fife and the Lothians—many instructive sections occur, where an abundant series of crinoids, corals, brachiopods, and other organisms, has been gradually or suddenly enveloped in a mass of tuff. Other instances likewise abound in which a suite of fossils may be found slowly struggling through the upper part of a bed of tuff, until the ashy sediment dies away, and the fossils gather together into a bed of limestone. Among the coal-seams, ironstones, and limestones of Scotland, such intimate relations to contemporaneous volcanic action may be traced. Or, lastly, we may study our trap-rocks with the view of learning under what conditions masses of melted rock are injected into strata and consolidated far beneath the surface, and how far the phenomena presented by such masses may be found to bear upon the subject of plutonic action and metamorphism.*

Viewed as rock-masses, and in relation to their connection with other rocks, Trap-rocks may be divided into two great groups:—1st, Those which have been thrust or injected into other rocks without reaching the surface, and which are consequently now exposed only as a result of the denudation of the rocks which once covered them, and under which they were consolidated. This may be termed the **Intrusive or Subsequent Group.** 2d, Those which actually reached the surface as true volcanic rocks, and came to be interstratified with and covered by the formation that happened to be in progress on the surface at the time.

* Geikie, Presidential Address to Section C, British Association, 1867.

To this group the name **Interbedded** or **Contemporaneous** may be assigned.

It must be borne in mind that these terms have reference only to the relation which the trap-rocks, so termed, bear to the rocks among which they occur. An *intrusive* mass, which is necessarily *subsequent* in date to the rocks through which it has been intruded, may be of the same date, or older or younger than another mass which is interbedded with its associated rocks. On the other hand, an *interbedded* trap, which is geologically *contemporaneous* with the rocks among which it lies, may be coeval with, or older or younger than, another trap which stands to its surrounding rocks in an intrusive or subsequent relation. The terms relate solely to the behaviour of the rocks as rock-masses, and to their chronological sequence relatively to the other rocks among which they occur.

This arrangement is one of great practical convenience to the field-geologist.* It is evident, however, that as all the trap-rocks, whether intrusive or interbedded, originated beneath the surface, they must all be in reality intrusive in some part of their mass. Those which reached the surface and spread out as wide sheets there, must first of all have been intruded through the rocks beneath the surface before they could appear at all, just as every modern lava-flow must be connected with some subterranean pipe or column of lava which has risen through older rocks, and is therefore *intrusive* or *subsequent* to them, though the lava-stream at the surface becomes *interbedded* with any modern deposits which may be in the course of formation at the locality, and is therefore *contemporaneous* with them. Nevertheless, in practice we seldom can connect the contemporaneous outflow at the surface with the intrusive column or pipe from which it proceeded. The crust of the earth is so broken and disjointed, and the rocks now visible to us are so fragmentary from dislocation and frequent and enormous denudation, that, as a rule, the utmost we can say is, that here is a series of igneous rocks which were actually ejected to the surface, and are consequently contemporaneous

* Yet it is of comparatively recent development. In the earlier days of geology it was the intrusive aspect of the trap-rocks that was chiefly insisted on by the Huttonians as evidence of the igneous origin of these rocks, while it was their interbedded aspect which was seized upon by the Wernerians as proof of aqueous deposition. The idea that many of the trap-rocks are of volcanic origin, and contemporaneous with the rocks among which they occur, was not unknown, as the writings of Faujas St Fond, Boué, and Macculloch, prove, and it was clearly made out by Sir R. Murchison in his original "Silurian System." But I believe the idea never bore fruit in any wide investigation of the rocks themselves until it was brought prominently forward and applied by the late Sir Henry de la Beche in the south-west of England, and afterwards by him and his colleagues of the Geological Survey in Wales and in Ireland. There can be no doubt that the work of the Survey was the first, as it is still the most memorable attempt, on a great scale, to apply the knowledge of recent volcanic action to the elucidation of the igneous rocks of ancient geological periods. (See the Maps and Sections of the Geol. Survey of Wales, and Professor Ramsay's Memoir on North Wales in the 3d vol. of the *Survey Memoirs*.)

with the formation in which they are interbedded; while there is another group wherein the parts of the rock now visible must have consolidated beneath the surface, for they have been injected into the rocks among which they occur, to which therefore they are subsequent. Every mass of interbedded trap must have been connected with an intrusive pipe or mass somewhere, whether now visible or not; but we cannot affirm that each particular mass of intrusive trap we meet with was ever connected by any upward prolongation with the surface that existed at the time of its intrusion. In studying the intrusive trap-rocks, we have to deal with the subterranean phenomena of volcanic action; in tracing the characters of the interbedded trap-rocks, we are brought face to face with those features of volcanic action which were displayed at the surface.

In the classification of rocks, already given in Chapter V., the trap-rocks were ranged in two main divisions, according to their lithological character and mode of production,—the Crystalline, consisting of rocks that had, like lava, consolidated from a state of igneous fusion; and the Fragmental, comprising those which had been formed from the consolidation of loose materials ejected from beneath the surface. That classification is retained here; but, instead of considering the composition, we shall now discuss the petrological characters of the rocks of each division, under the heads Intrusive and Interbedded.

I. INTRUSIVE OR SUBSEQUENT TRAP-ROCKS.

A. CRYSTALLINE.

If the student has mastered the description of the crystalline trap-rocks already given, he will recognise that, possessing the one common character of having solidified from an original melted condition, they may occur either as intrusive or as interbedded masses. There are some, however, which are never met with but in one of these forms, others which usually occur in the other, and some which may be encountered indifferently in either. The diorites, for example, are always intrusive rocks.* The basalts, on the other hand, usually form interbedded sheets and beds, though often found also in intrusive positions. The felstones occur sometimes in the form of interbedded sheets, and sometimes in intrusive veins or masses. In Britain, as a rule, the coarsely crystalline varieties of trap are of intrusive character, while the interbedded traps are commonly finer-grained and often amygdaloidal. To this general rule, however, there are so many exceptions, that the student would not always be safe in pronouncing a particular rock to be certainly intrusive or otherwise, merely from its texture, and without reference to the geological structure of its locality; a little practice,

* That is, of course, when they are not to be regarded as of metamorphic origin.

however, will enable him to decide with tolerable accuracy in this matter.

The intrusive character of trap-rocks may be examined under two aspects. In the first place, we may consider the origin of rocks which have manifestly solidified at a great depth beneath the surface, and which may be connected with the fusion and alteration of subterranean masses during the process of *Metamorphism*. In the second place, we may study other masses which probably solidified at a less depth, and indicate the extravasation of molten rock to the surface. In the former instance we deal with what may be called Plutonic trap-rocks, and in the second with rocks which are downward prolongations of the volcanic trap-rocks. This is a distinction which can be readily recognised in theory, though not always very easy to observe in practice. Our knowledge indeed of metamorphism and its cognate subjects is still so vague, that the study of the deep-seated trap-rocks is surrounded with much difficulty. The following observations, therefore, are designed to make the student acquainted simply with the petrological relations of these rocks, that is, with the forms which they assume as rock-masses, and the manner in which they are related to other rocks with which they come in contact. We shall not attempt in this place to decide which masses had an original upward prolongation and connection with true volcanic rocks, and which resulted entirely from deep-seated or plutonic action, but describe those features which must be understood before any theory as to origin can be reasoned on.

The intrusion of melted rock among other rocks within the earth's crust has been governed by one general law—viz. that the melted rock always tends to find escape along the lines of least resistance. In many cases we can determine what the lines of resistance were. Sometimes they were lines of fault or fracture, sometimes lines of bedding, sometimes lines of valley, or of some particular formation. In other cases the lines were many, or complex, or such that we cannot now trace them. It will be seen that these features conveniently determine for us the arrangement of the crystalline intrusive trap-rocks, which it is proposed to follow in the following pages. According to the nature of the line of escape along which the melted rock was intruded, we have α Amorphous Masses, β Sheets, γ Dykes and Veins, and δ Necks.

α. Amorphous Masses.

In many regions, diorite, felstone, and some of the earlier doleritic rocks, have broken through older formations in such an irregular manner, and in such volume, that they now show above ground in the form of huge amorphous masses. Their boundaries at the surface are more or less indeterminate, and when we can discover any section showing their relation to the rocks around them, we find the latter broken

and altered. Strata are abruptly truncated, and veins from the intrusive rock are often found penetrating between and among them (Fig. 98). Sandstone, as it approaches the junction, becomes harder and

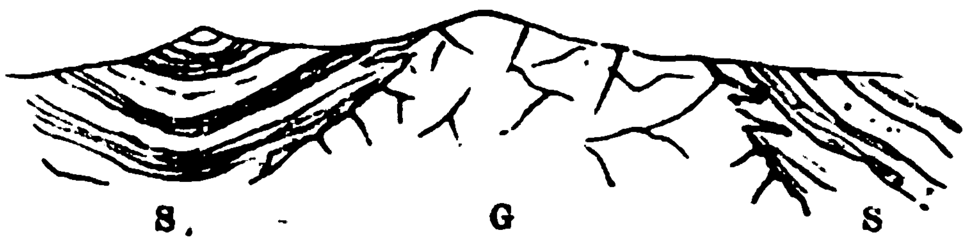

Fig. 98.
Amorphous Greenstone Mass (G) of Craig-das-Eithan, Wales, cutting through Lower Silurian rocks (S). [Prof. Ramsay.]

passes into quartz-rock. Shale gets more and more indurated, till it takes the form of porcelain-jasper, or some of the other varieties of altered argillaceous rocks. Limestone becomes much harder and more granular, sometimes passing into marble, and sometimes becoming veined with serpentine, and undergoing dolomitisation. Perfect crystals, as of garnet, analcime, pyrites, calcite, etc., are also sometimes developed in the altered rock.

Such, in especial, is the character of the diorites, felstones, and quartziferous porphyries of the palæozoic formations. In Wales, for example, the Lower Silurian rocks are pierced by huge masses of diorite (greenstone), which sometimes run for some distance along the line of strike of the stratified rock, and then break abruptly across it. These masses are frequently found to branch, and the rocks which they traverse have been greatly altered by them. Conspicuous examples are furnished in the Breidden Hills, Cornden Hill, and Craig-das-Eithan (Fig. 98). Of the greenstones in the Snowdon district Professor Ramsay remarks, "it seems probable that, like the great lines of greenstone between Llanberis and Ffestiniog, and between Moelwyn and Nant Gwynant, their tendency has been to force their way in between the lines of bedding; but from causes, difficult or impossible to trace, they have also branched underground hither and thither with considerable irregularity, and now, when exposed by denudation, crop out apparently in a capricious manner."* Some of the Welsh greenstones are amygdaloidal —a circumstance which may perhaps connect them with volcanic phenomena. Sometimes they are columnar.

In the Lower Silurian and Old Red sandstone formations of Scotland, large masses of felstone and various porphyries have been intruded among the strata. In the Carboniferous formation of the same kingdom a similar part is played by doleritic trap-rocks, and sometimes, as in the neighbourhood of Edinburgh, by diorite.†

* *Mem. Geol. Surv.*, vol. iii., p. 128. See also Sir R. Murchison's *Siluria*, chap. iv., and *Catalogue of Rock Specimens in Jermyn Street Museum*, p. 6, *et seq.*

† See *Catalogue of Rock Specimens in the Edinburgh Museum.*

β. Sheets.

Mode of Occurrence.—Among the lines of weak resistance to the passage of intrusive trap, none have been more constantly made use of than those furnished by the divisional planes of stratification. When a mass of melted rock has been intruded between the planes of bedding of strata, it takes the form of a sheet or bed, varying in thickness from less than a foot to several hundred feet. Sometimes this has been effected in such a way, that in the parts now visible no disturbance of the strata can be detected, the intruded rock lying regularly and conformably between them, as if it formed an original part of the series (Fig. 99).

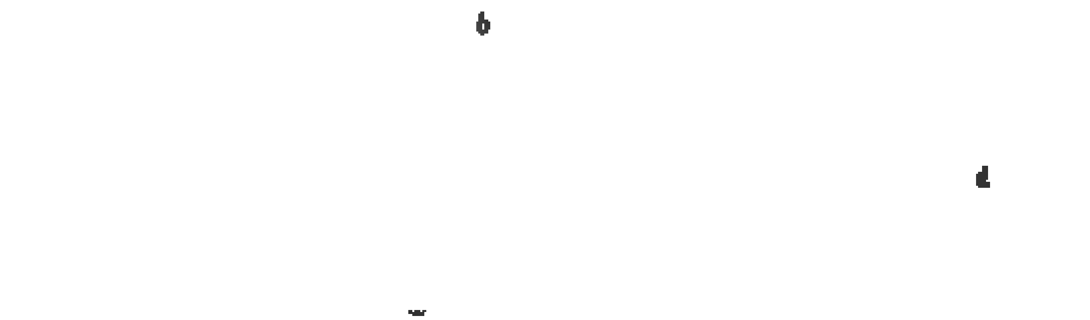

Fig. 99.
Intrusive sheets of dolerite (melaphyre). Edinburgh.
a. Sheet forming St. Leonard's Crags. b. Sheet forming Salisbury Crags.

These two sheets come together, and form the thick rudely columnar mass of Samson's Ribs (c). It will be observed that these sheets partly conform to the bedding of the carboniferous sandstones and shales (d), and partly cut across them.

In such cases great care is required to make it certain that the rock really is intrusive. Yet, if the student examines the lines of junction of the upper and under sides of the trap-rock with the contiguous strata, he will find that the strata have been hardened for some inches, or even sometimes for some feet, away from the intrusive sheet. This is particularly to be searched for along the upper surface, for if the strata resting upon that surface are altered, it is clear that the trap is intrusive and subsequent. This is an infallible test of the intrusive character of a trap-rock. It very commonly happens, moreover, that the texture of the trap becomes much more compact towards its contact with the stratified rocks—a circumstance which, when it occurs along the upper surface, helps to prove the intrusive character of the mass. We shall see, in a subsequent part of this Chapter, that truly interbedded trap-rocks do not usually become finer-grained along their upper surface, but have a totally different character. The change in texture is probably due to the more rapid cooling of the edges of the melted mass by contact with the strata among which it was thrust, while the central portions, cooling more slowly, assumed a more distinctly crystalline texture.

A perfect conformity with the bedding above and below is, however, not the rule with intrusive sheets. More usually, while conforming to it in a general way, they are found here and there cutting across one or more beds (Fig. 100), catching up, involving, and "baking" portions of them, and sometimes breaking away altogether from their previous course, striking across the beds, and taking a new line along the strike of a different part of the series. These irregularities show at a glance that the rocks which display them have been intruded along and across the planes of bedding of the stratified formations.

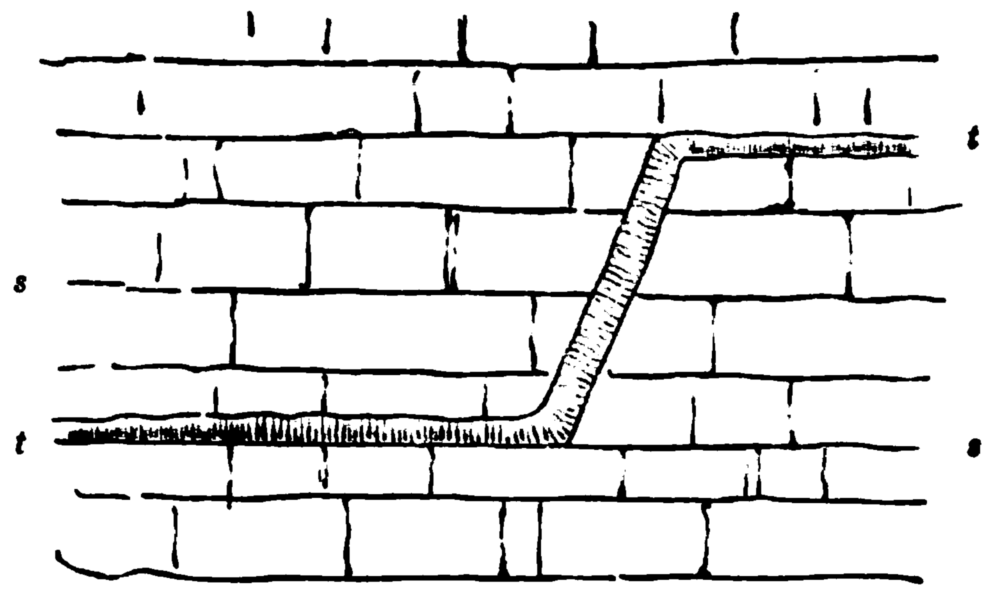

Fig. 100. (From previous edition of this Manual.)
s. Stratified rock.
t. Trap running partly between, partly across the beds.

Some continental geologists make a difficulty in allowing the true intrusive character of many such sheets from their great thickness, the depth of rock which, on the supposition of their intrusion, must have covered them, and the absence or trifling nature of the observable disturbance of the strata overlying them. If we could attach any weight to the objection on the score of the thickness of the mass and the enormous pressure of the overlying rocks, we might on the same ground deny the possibility of volcanic eruptions; while the small amount of disturbance sometimes effected on the under surface of the overlying beds is not more than we might reasonably expect occasionally to happen when a mass of molten rock forced itself along a yielding bedding-plane between two groups of compact strata.

Lithological Character.—All, or almost all, the varieties of the crystalline trap-rocks may be found in the form of intrusive sheets. The diorites of Wales commonly occur as long bands which have risen along the strike of the strata.* The intrusive felstones, minettes, and syenites of the Silurian region of the south of Scotland have been thrust along the line of bedding, and may sometimes be traced for miles running parallel with, but often breaking into, the greywackes and shales among which they lie. The diabases and doleritic rocks of the Carboniferous formation of Scotland occur abundantly as intrusive sheets among the sandstones, shales, and other strata; and, as they are much harder than the latter, they tend to stand up in prominent crags. The mural

* See Professor Ramsay's Memoir on North Wales. *Mem. Geol. Surv.*, vol. iii.

escarpment of Salisbury Crags, at Edinburgh, is a familiar illustration (See Fig. 99).

Varieties of Structure and Texture.—Trap-rocks which occur as intrusive sheets have usually an amorphous internal structure—that is to say, they are divided more or less irregularly by joints, but have no definite and regular lines of division. Sometimes, however, as in the case of the Welsh greenstones above mentioned, they are columnar, and even show curved columns, as in the basalt of Staffordshire (Fig. 101). Occasionally they assume a rudely fissile character, as in some

Fig. 101.
Curved columns in dolerite. Pouk Hill Quarry, Staffordshire.*

compact felstones. They are frequently porphyritic, and this is especially true of the felspathic series. Rarely they are amygdaloidal. As a rule, the central parts of a sheet are larger grained than the edges. This may often be strikingly seen among the dark augitic rocks, where the exterior (upper or under) portions become more and more compact, until the individual crystals can no longer be recognised, and the rock passes into a close-grained diabase or melaphyre. This change has already been alluded to as probably due to a more rapid cooling of these close-grained external parts. In cases where the trap has come in contact with highly ferruginous or calcareous rocks, it has often undergone a further change from a series of chemical reactions. The iron or lime has been infiltrated into its outer parts, which are found to be often veined with hematite, calc-spar, or serpentine. Still more striking is the change effected upon doleritic rocks from contact with

* From Jukes' *School Manual of Geology*, Fig. 9.

carbonaceous shale and coal. The trap in such cases is converted into a soft white or yellow wacke or clay for some inches from the edge, and if the sheet happens to be only a foot or so thick, and to have been intruded along the lines of parting of a coal-seam, it may be found completely altered from one side to the other. Such altered trap was referred to in Chapter V. (p. 105), as occurring in Staffordshire under the name of "white rock." It is likewise abundant in Ayrshire. In that coalfield the intrusive sheets in many cases have chosen their paths along the course of coal-seams, probably because these seams offered less resistance to their passage than the more stubborn sandstones and shales.

"Contemporaneous Veins."—It is not uncommon to find intrusive sheets of crystalline trap-rock traversed by long narrow branching veins of the same rock as the rest of the mass, but distinguished from the rest by being lighter or darker in colour, coarser or finer in grain, more or less porphyritic, or with a greater predominance of one of the component minerals. These veins are often met with among the hornblendic and augitic traps. They vary in thickness from an inch or less to a foot or more, and commonly tend to run in a general way parallel with the bounding surfaces of the mass in which they occur. The subjoined sketch (Fig. 102) illustrates the way in which these veins

Fig. 102.
"Contemporaneous veins" in diorite. Ratho, near Edinburgh.

occur in a large intruded sheet of diorite, which lies among the sandstones of the lower carboniferous formation near Edinburgh. The name "contemporaneous veins" was given to such intruded veins and threads by the Wernerian geologists in the early part of this century, under the belief that they were all deposited from aqueous solutions, along with the crystalline masses in which they are found. We may retain the name, but for the purpose of expressing that the veins belong to the same intrusion as the masses which contain them. They

seem in certain cases to have been produced from some movement of the whole mass during consolidation, whereby yet fluid portions were injected along cracks or between divisional planes of the mass. In other instances, where they are found to merge into the surrounding rock along both their bounding surfaces, they rather suggest the idea of segregation and crystallisation of the minerals along particular lines.

Alteration of Stratified Rocks.—The effects produced by intrusive sheets upon the stratified rocks with which they have come in contact are generally similar to those already referred to as characterising the boundary-lines of amorphous masses. They differ, however, in this respect, that we have often before us a more decided intrusion and prolonged line of contact when we examine the behaviour of an intrusive sheet. The melted rock has come into more intimate relations with the stratified beds, and the phenomena of alteration by heat are thus more easily followed into detail. When a sheet of diorite, melaphyre, or other trap-rock, has been intruded among sandstones, the latter are usually hardened along the junction to a depth varying from an inch or two up to several feet. This induration has sometimes proceeded so far as to convert the rock into a quartzite. Sometimes, besides the induration, the sandstone has had a system of prismatic joints superinduced upon its structure, whereby it splits off in columns, the ends of the columns springing at a right angle from the surface of the sheet, in the same way that a columnar structure is found sometimes generated in the sandstone-slabs used to line furnaces. Shale is likewise hardened, and sometimes converted into a kind of porcellanite or flinty slate. The shales traversed by the diorite sheets of Wales are changed into a hard rock used for honestones ; and the famous "Water-of-Ayr Stone" is likewise a shale, probably hardened by the proximity of some of the great sheets of dolerite by which the Ayrshire coalfield is traversed. But the most striking cases of alteration are those in which the sheet has been thrust along the bedding of highly carbonaceous shale or of coal. The dolerite (or melaphyre) is then itself altered as above described, and the best coal-seam is so changed as usually to be rendered quite worthless. The nature of the change varies with the thickness, and perhaps with other original conditions of the doleritic sheet. Most frequently the coal is found first to become hard and brittle, passing into a kind of anthracite or "blind-coal;" it then gets more and more broken and friable, until, as it comes near the dolerite, it is a mere black ash or soot. Some remarkable instances of this kind occur in the South Staffordshire coalfield. Fig. 103 represents above 100 yards of the Tenyard coal in the Grace Mary Colliery, where the coal is traversed by sheets and strings of "white rock" connected with the basalt hills of that district. The coal has there "lost its bright lustre

and its regular 'face,' and has parted with much of its bituminous or inflammable character, and more nearly resembles anthracite than

Fig. 103.
Coal altered by "white-rock" trap. South Staffordshire.
a. "White-rock" trap. b. Altered Coal. c. Sandstone.

bituminous coal, though different from both, being often full of concretions of iron pyrites, or of carbonate of lime, or other minerals."*

In the Ayrshire coalfield some remarkable cases of the alteration of coal occur, where the coal has not only lost its ordinary so-called bituminous character, but has assumed a fine columnar arrangement. Near Dalmellington, and again near Kilwinning, sheets of dolerite, sometimes only about a foot thick, have been injected along the middle of a coal-seam, so as to divide the seam into two, the separated portions being each rendered columnar. The columns are five and six sided, about the thickness of stout pencils, and diverge from the surface of the trap in the same way that the much larger and coarser columns of sandstone do.†

Though coal is usually found to be considerably altered where it comes in contact with or even approaches any mass of intrusive igneous rock, yet cases occur where little or no change is observable. A remarkable example was noticed by the writer at the Townhill Colliery, Dunfermline, where a coal-seam has been worked up to the surface, with a sheet of melaphyre for a roof. The coal is a little hardened, but not charred or rendered unworkable, while the trap, which in its central parts is compact and finely crystalline, becomes earthy in texture where it meets the coal below it and the shales above.‡

It is worthy of remark that when a coalfield is much troubled with intrusive sheets of trap-rock, these are commonly found to have chosen their path along the line of coal-seams—a circumstance already alluded to as evidence of the tendency of subterranean igneous rocks to escape upward along the lines of least resistance. In one district, that of Linlithgowshire, where there is a great abundance of intrusive trap, traversing rocks among which highly bituminous shales and coal-seams occur, a process of destructive distillation seems to have taken place.

* See this and other examples described by Mr. Jukes in his *South Staffordshire Coal-field*, 2d edition (*Mem. Geol. Surv.*) The trap which destroys the coal mentioned above is the same as that of which an analysis is given on p. 105.

† See *Catalogue of Rock Specimens in Edinburgh Museum*, p. 81.

‡ See *Mem. Geol. Surv.*, Geology of Edin., p. 65, *note*.

The joints of the sandstone are in one place filled with asphaltum, while petroleum occurs in globules in the cavities of the intrusive rocks. Even where these substances cannot be detected, the dolerite, when freshly broken, has a distinct naphtha-like odour, as if the melted rock had invaded the carbonaceous beds and become impregnated with the products of their distillation.*

γ. Dykes and Veins.

It frequently happens that the line of least resistance to the upward movement of melted rock beneath the surface has not lain along the planes of stratification, but at a greater or less angle to these planes, along fissures of the rocks. In such cases, instead of intrusive sheets, we have *dykes* and *veins*. When the injected mass has risen along an opened fissure, and solidified there as a wall-like intrusion, it is called a dyke. When its path has been less regularly defined, and penetrates the surrounding rocks in a wavy thread-like fashion, this irregular protrusion is called a *vein*. Between these two forms, however, there is no essential difference; many dykes send out veins, and sometimes what would be called a dyke at one part of its course passes into what would be termed a vein at another. As a rule, however, we may say that veins occur in the vicinity of, and in connection with, large intrusive masses of igneous rocks, while dykes frequently abound where there is no other evidence of any igneous rock at or near the surface.

Fig. 104.
Basalt veins in Cambrian conglomerate. Isle of Raasay.

Veins vary in size from mere strings or threads up to branching masses, many feet or yards in thickness. As already remarked, they

* See *Mem. Geol. Surv.*, Geology of Edin., p. 116.

occur most commonly in connection with some larger intrusive mass, not unfrequently proceeding from dykes. They can seldom be traced far, differing in this respect very markedly from dykes. Sometimes they are found to rise through a mass of rock and pass into an overlying sheet of trap, as if they had been the pipes or channels through which the sheet had been erupted. While dykes are either vertical or highly-inclined wall-like masses, veins may occur at any angle, or may even run horizontally between strata, as if they were themselves beds. Hence veins may pass into intrusive sheets. It often happens that veins subdivide into two or more branches, whether their course be vertical or horizontal.

Dykes vary in thickness from less than a foot to seventy feet or more. They usually ascend either vertically through the rocks which they traverse, or at a high angle. Sometimes they cannot be traced horizontally more than a few feet; in other cases they can be followed for thirty, forty, and even sixty miles. Thus, a well-known dyke fifty or sixty feet thick extends from the coast of Yorkshire in a straight line north-west for at least sixty miles, cutting in its course every formation, from the lower Oolite down to the lower Carboniferous. How far dykes descend into the earth we have no means of ascertaining, and as they must in all cases have risen from some melted mass of rock within the crust of the earth, there is no reason to doubt that, if we could follow them downwards, we should find each dyke continuous until it passed into its original parent mass.

One of the most remarkable features of trap-dykes is the singular evenness of their sides. As a rule, they rise through the other rocks literally as walls, the two opposite surfaces of each dyke running as parallel to each other as those of a wall of masonry, and usually much smoother than a mason's work. This feature is often seen to striking effect where the dykes have risen through shales or other soft rocks which have been worn away, so as to leave the intrusive rock standing up as tall perpendicular walls. Such is the case in the Western Islands, where also the reverse may often be seen, the dykes having decayed, and left open the long, deep, and narrow rifts which they once filled.

While instances do occur in which the dykes have filled very uneven fissures, the prevailing regularity of their thickness and direction tends to show that the igneous rock has not itself been directly the cause of the fissures. These have much more probably been due to the action of a general powerful agency, of which the extravasation of the igneous rock is only itself additional evidence. There is reason to believe that in many, if not in most cases, the fissures existed before they came to be widened and filled with intrusive rock, so as to become dykes. This is especially the case where they have not been mere

rents in the crust of the earth, but rents attended with the upheaval or depression of one or both of the sides—that is to say, faults. We find dykes coinciding with such lines of fault, but in such a way as to show that the faults are of older date, for the dykes are found also to cross the faults without being deflected thereby.

Trap-Dykes of Britain.—In perhaps no part of the world can these and the other characteristic features of trap-dykes be more satisfactorily studied than in that area of the British Islands which extends from the north of the island of Skye southwards through the midland and southern tracts of Scotland, the north of England, and the north-east of Ireland.* "If, starting from the great tertiary basaltic plateaux of the north of Ireland or of the Inner Hebrides, we advance towards the south-east, we soon observe that an endless number of trap-dykes, striking from these plateaux, extends in a south-easterly direction athwart our island. The south-western half of Scotland and the northern parts of England are, so to speak, ribbed across with thousands of dykes. These are most numerous near the main mass of igneous rock, whence they become fewer as they recede towards the North Sea. Usually a dyke cannot be traced far: it has not been ascertained that any single one can be followed completely across the island, though the well-known Cleveland dyke in the north of England runs for at least 60 miles, cutting in its course Carboniferous, Permian, Triassic, Liassic, and Oolitic rocks, till it reaches the sea on the coast of Yorkshire, at a distance of more than 200 miles from the nearest point where the sheets of Miocene trap are now visible. In Berwickshire and the Lothians, these E. and W. or N.W. and S.E. dykes, often less than a furlong in length, are well shown; in Ayrshire they become still more numerous, traversing the coalfield and altering the coal-seams; in Arran and Cantyre their number still increases; until, after a wonderful profusion of them in Islay and Jura, they reach the great volcanic chain of the inner Hebrides. From their manifest intimate connection with that chain, from the fact that they cut through all the formations they encounter up to and including the Chalk, and that they cross faults of every size that may lie in their way, these dykes are regarded by the writer as of Tertiary age. If this inference is sustained, as it probably will be by a more detailed investigation of the north-western districts, it presents us with striking evidence of the powerful activity and wide range of the volcanic forces in our country during the Miocene period.

There are, perhaps, few parts of the geology of the country so hard to understand as the extravasation of the thousands of dykes by which the north-western portion of this island is so completely traversed.† We find these dykes rising to the surface, and extending for leagues to a distance of fully 200 miles from the nearest point of the basaltic plateaux. Did they reach the surface originally? If so, were they connected with outflows of dolerite, now wholly removed by denudation? I confess that this supposition has often presented itself to me as carrying with it much probability. It seems to me unlikely that so many thousands of dykes should have risen so high as the present surface, retaining there (as shown by deep mines) much the same proportions as they show

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* The above remarks in small type, upon the trap-dykes of Britain, are from the Presidential Address to Section C of the British Association, 1867. Dundee.

† Boué felt this difficulty, but he conceived that the fissures had been filled from above by masses of basalt, erupted at different points, and spreading over the country, though now removed by denudation. He says—"Nous croyons infiniment probable que ces filons ont tous été formés de même [*i. e.* remplis par des courans de lave dans leur marche], malgré les grandes destructions qu' entraine cette supposition, et que rarement il y en a eu quelques-uns qui ont été remplis latéralment ou de différentes manières bizarres."—*Géol. d'Ecosse*, p. 272.

many fathoms down, and yet that none of them should have reached the surface which existed at the time of eruption. I regard it as much more probable that some of them, at least, rose to daylight, and flowed out as *coulées*, even over parts of the south of Scotland and north of England, where all trace of such surface masses has long been removed. Some of the surface-masses of dolerite in these districts may indeed be of Tertiary age; yet the proofs which the great Miocene basaltic plateaux present of enormous denudation are so striking as to make the total disappearance of even wide and deep lava-currents quite conceivable.

But a much more serious difficulty remains. These dykes, as a rule, do not come up along lines of fault, yet they preserve wonderfully straight courses, even across fractured and irregular strata. Each dyke retains, as a rule, a tolerably uniform breadth, and its sides are sharply defined, as if a clean, straight fissure had been widened and filled up with solid rock. More than this, they are found cutting across large faults without any deflection or alteration. In short, no kind of geological structure, no change in the nature of the rocks traversed, seems to make any difference in the dykes. These run on in their straight and approximately parallel courses over hill and valley for miles. The larger faults of this country tend to take a north-easterly trend, and correspond in a general way with the strike of the formations. At right angles, or more or less obliquely to these, are numerous faults of lesser magnitude, which follow roughly the dip of the rocks. But though these different systems of fissures already existed, and, as we might suppose, would have served as natural pathways for the escape of the subterranean melted rock towards the surface, the latter rose through a new series of fractures, often running side by side with those of older date. How were these new fractures produced, and how is it that they should run through all formations, up to and including the older parts of the Miocene basalts, not as faults, with a throw on one side, but as clean straight fissures, with the strata at the same level on each side? I do not pretend to answer these questions. Let me only remark that, had the trap-rock been itself the disrupting agent, it would have risen through the older fractures which already existed as the planes of least resistance. The new fissures must be assigned to some far more general force, of the action of which the trap itself perhaps furnishes additional evidence."

Lithological characters of Trap-dykes and Veins.—The rocks which occur in the form of dykes are usually of the pyroxenic division—dolerite, melaphyre, or diabase. More rarely diorite is found in this form, and still more uncommonly members of the felspathic division. All these rocks, however, occur as veins.

As in intrusive sheets, the internal parts of dykes are usually more coarsely crystalline than the outer portions. They are occasionally minutely amygdaloidal, the kernels being arranged in lines parallel with the sides of the dyke. Such lines of kernels are most marked along the centre of the dyke, and diminish in number and in the size of the kernels as they approach the edges. Among dykes of dolerite the closeness of grain sometimes proceeds to such a degree that, along the outer surfaces, the rock, where it comes in contact with the surrounding rocks, passes into a black glassy or pitch-like substance, called *tachylite*. This external coating varies from a mere film up to nearly an inch in thickness. It has been confounded with pitchstone, which externally it closely resembles,* but true pitchstone is a highly siliceous

* This mistake has been made by even so good a mineralogist as Dr. Macculloch. See

rock, while tachylite is quite basic. The latter is the glassy form of dolerite (or basalt), while the former is the glassy form of felstone or one of the acidic rocks. The glassy film on the edge of these dolerite dykes is probably due to the rapid cooling of the mass where it came in contact with the surrounding rock. Reference has already been made to the artificial fusion of a doleritic rock, and the production of a black pitchstone-like glass by quick cooling.* Sometimes the line of fissure occupied has served for more than one protrusion of igneous rock. This gives rise to what may be termed a compound dyke, where, instead of one rock occupying the whole of the fissure, there are two or more parallel strips of different rocks. This may be noticed among the tertiary dykes of Skye and other parts of the Western Highlands. The same dyke sometimes contains dolerite and basalt, or dolerite and syenite, the one rock having been injected after the injection and consolidation of the other.

Varieties of Structure.—In some cases it happens that a dyke consists of an amorphous mass of rock, with no very well-marked divisional planes. But as a rule dykes are traversed by joints, of which two sets are often well developed, one crossing the dyke from side to side, at right angles to its course, the other running parallel with the length of the dyke. These two systems are perhaps better displayed in dolerite dykes than in dykes of any other rock. The longitudinal series is now and then so strongly marked in these dykes that the rock looks as if it consisted of a series of thin strata placed on end. A less common feature, but one which is also more frequent among dykes of dolerite or basalt, is the columnar structure. When a dyke shows this structure, the columns (hexagonal or polygonal, or sometimes rather irregular) strike at a right angle from the cooling surfaces, that is from each side of the dyke, inwards towards the centre. Sometimes the columns do not reach the centre, which shows an irregularly jointed structure. In other cases they meet in the centre, but not symmetrically, those from the one side not being continuous with those from the other, but joining them along a more or less irregular and indefinite line. But in some examples each column or prism can be followed completely across the dyke from side to side. The columns are of course

his *Classification of Rocks*, p. 526. Professor Jameson has committed the same error in his *Geology of Dumfriesshire* (p. 115), where he speaks of pitchstone passing into basalt among the Silurian rocks of Galloway.

* The experiments of Sir James Hall, in the early part of this century, were the earliest in which physical and chemical research was employed in the service of geology. He fused a number of the "whinstones," or augitic trap-rocks of the neighbourhood of Edinburgh, and produced, by rapid cooling, a black glass, and by slow cooling a crystalline mass closely resembling the original rock. In his remarkable memoir, in which these experiments were described (*Trans. Roy. Soc.*, Edin., 1798, vol. v., p. 43), he referred to the occurrence of a vitreous external surface on some of the dykes of Monte Somma observed by himself. The same experiments have since been repeated with similar results.

horizontal when the dyke is vertical, just as they are vertical when the sheet or bed in which they occur is horizontal. In either case they spring from the planes of cooling, which in the dyke are its two walls, and in the sheet its upper and under surfaces.*

Alteration of Contiguous Rocks by Dykes and Veins.—The same appearances of metamorphism are often visible along the edges of dykes, as already mentioned in the case of amorphous masses and intrusive sheets. The most common change is the hardening of the contiguous rocks, shales passing into porcellanite or flinty-slate, sandstones into quartzite, and so on. Sometimes a columnar structure is developed in the rocks, as in the sandstone next a dolerite dyke near Glasgow. Coal suffers greatly, being converted into a kind of soot close to the dyke; into charred cinder or "clinker" a little further off, then into "blind coal," or a form of anthracite, until the ordinary character of the seam is resumed, but sometimes not at a less distance than thirty or forty yards. New minerals are likewise developed under favourable circumstances. Calc-spar, bitter spar, garnet, analcime, galena, pyrites, and other minerals are occasionally found well crystallised in the rocks bordering a dyke.† Cases abound, however, where the amount of visible alteration along the sides of dykes is very trifling, or where no alteration can be detected at all. The lias shales of Pabba, in the Inner Hebrides, are traversed by many basalt dykes, but they are scarcely even a little hardened. These variations would largely depend upon the nature and condition of the rock to be operated upon, as well as on those of the heated rock or vapours which rose through the fissure.

δ. Necks.

It sometimes happens that, as a result of great denudation, the pipe or orifice is disclosed by which sheets of melted rock or showers of dust and stones have been ejected from below—in other words, the chimney of the old volcano. Such orifices are not, however, now empty, but are always filled with some kind of trappean material. In this condition they are called *necks*. They may be choked up either with some form of crystalline or of fragmental rock, according to the nature of the final eruptions. They are usually of an oval or irregularly rounded form on the surface, and vary in breadth from a few feet to two or three hundred yards. They of course descend to an unknown depth below, and they must once have risen higher than the present surface, which is one of extensive denudation. As it is only owing to the results of denudation that any are visible at all, the number we can see must be very much smaller than the number buried under overlying rocks.

Where no important subsequent disturbance of the crust of the earth has taken place at the locality, a neck descends vertically or

* See *ante*, p. 182. † See Henslow, *Cambridge Trans.* i., 410; Sedgwick, *Op. cit.* ii., 175

nearly so into the interior of the earth. But, if any great movement of the rocks has happened, the neck may be inclined at a considerable angle with the horizon. So that a neck coming through horizontal, or gently inclined strata, will always be approximately vertical, while, if the strata are subsequently tilted, the neck will be proportionately inclined to the horizon, though of course remaining perpendicular to the bedding of the stratified rocks. All igneous rocks, whether interbedded or intrusive, when once they have consolidated into rock-masses, are subject to the same subsequent fractures and tiltings as the rest of the crust of the earth.

Necks sometimes entirely consist of felstone, diorite, melaphyre, porphyrite, or some other species of the crystalline trap-rocks. In such cases the rock is usually more compact, and occasionally more largely crystalline, than the sheets of the neighbourhood. At other times the necks are found to be made up wholly of a coarse trappean agglomerate, in which large blocks of melaphyre, porphyrite, etc., are mingled with fragments of the contiguous or under-lying rocks, in a rough gravelly base of trap-tuff. To such agglomerate necks masses of slaggy melaphyre are sometimes found adhering externally, indicating the nature of some of the previous ejections before the orifice became finally choked up with the coarse volcanic detritus.

Where a section of the rocks surrounding one of these necks can be examined, the former are found to be much affected. In the first place, we find it to be a very general rule that strata are bent down so as to dip into the neck all round its margin. This is the reverse of what we might have expected, yet it has been found to be almost invariably the case wherever the writer has been able to examine the line of junction. In the second place, the surrounding rocks are altered evidently by the influence of great heat, and probably too of gaseous and other vapours. Sandstones are hardened, and have a broken blistered look ; shales are changed into jaspery textures ; coal-seams are completely charred, and destroyed for some distance round the neck.

Fig. 105.
Section of porphyrite neck. Haddingtonshire.

In Fig. 105 is shown a section of a small "neck" of porphyrite in lower carboniferous sandstones on the shore near the mouth of the Tyne, Haddingtonshire.* The way in which the beds dip in towards the neck can be examined in detail along the beach.

* *Mem. Geol. Surv.*—Geology of East Lothian, p. 40.

B.—FRAGMENTAL.

It is usual to exclude altogether the fragmental forms of trap from the intrusive series. Yet, from what has been said in the immediately preceding paragraphs, the student will perceive that fragmental rocks occur as *necks*, and in that form are truly intrusive in relation to the rocks which they traverse. The intrusive character of these necks or volcanic orifices, however, differs from that of most crystalline intrusive trap-rocks, inasmuch as the necks plainly point to the action of true volcanoes, and not only so, but show us the nature of the material which, ejected from the chimney of the volcanic focus, fell back into it again, and finally consolidated there, so as to fill up the pipe, while, on the other hand, the portions of the intrusive crystalline trap-rocks now visible consolidated at some depth, and did not reach the surface, nor in many cases were connected with volcanic action at all.

The fragmental materials filling many old volcanic chimneys, and now forming necks, consist of a coarse tumultuous agglomerate. The stones vary lithologically, according to the nature of the crystalline trap-rock which happened to be in fusion below at the time of the eruptions, and according to the character of the rocks through which the volcanic pipe was blown open. Sometimes the agglomerate consists of blocks of porphyrite, red sandstone, red marl and shale, imbedded in a rough paste of the same materials still further comminuted. In other places it is made up of blocks of melaphyre, diabase, white and grey sandstone, dark shale and limestone. In the broad carboniferous valley of Ayrshire the writer has found even a fragment of granite in one of these agglomerates, where the nearest granite, either in place or in any conglomerate, must be at a great depth.

While, probably, most necks of fragmental materials consist of coarse unstratified trappean agglomerate, they are sometimes composed of finer tuff, and in such cases the tuff is partly stratified. The stratification, however, is of a most remarkable and irregular kind. The beds (which are often well marked) dip in all directions, and at all angles, frequently being on edge. The sandstones around the edges of the neck are much hardened, and portions of them project into, and have been enveloped in, the tuff.*

The remarks made in the previous section of this chapter as to the size of necks, their external form, and their effects on surrounding stratified rocks, are equally true where the necks consist of agglomerate.

In a few instances veins of agglomerate, similar to that of the necks, have been observed filling up cracks of the surrounding rocks.

Necks of coarse agglomerate rise abundantly through the carboniferous rocks of the midland valley of Scotland, particularly in Ayrshire,

* See *Geological Survey Memoirs*—Geology of East Lothian, p. 44.

where they are mainly of Permian age.* A plan of one of these necks, traversing lower carboniferous strata on the shore at Dunbar, is shown

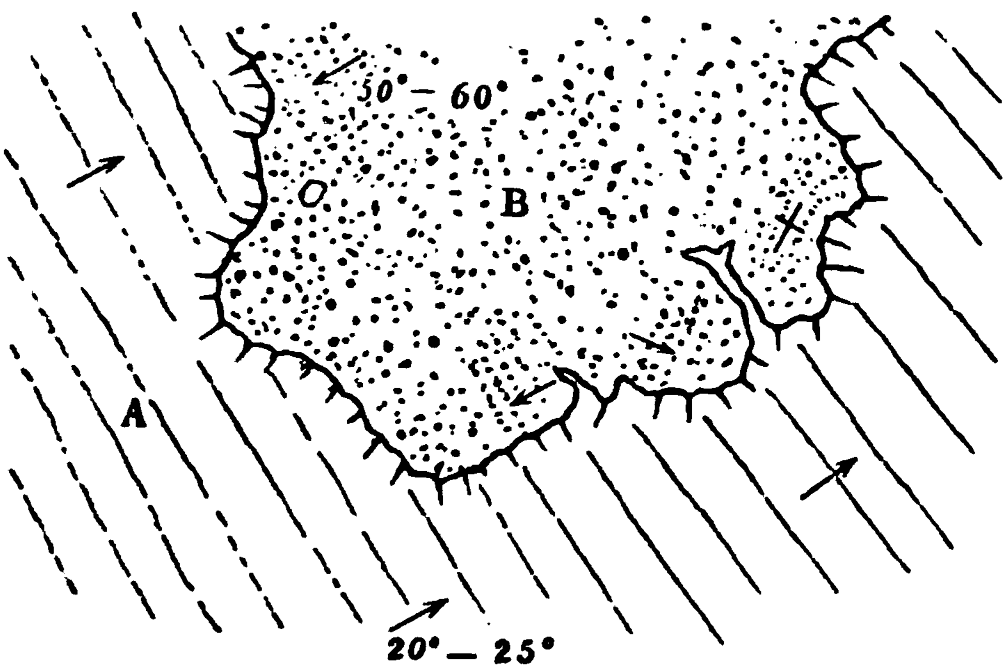

Fig. 106.

Ground-plan of part of a neck of tuff in Lower Carboniferous Sandstone. Dunbar.

A. Lower Carboniferous sandstone. The parallel lines mark the strike of the strata, which dip at an angle of 20°-5° in the direction of the arrows. The cross lines round the wall of the neck indicate the extent of the induration of the sandstone.

B. Tuff, well stratified in places, dipping in various directions, as shown by the arrows, and at angles varying from 50° to 90°. Tongues of the sandstone protrude into the neck, and fragments of the same rock are enclosed in it.

in Fig. 106. The sandstones round the agglomerate are much hardened, and portions project from the walls of the cavity into the agglomerate,

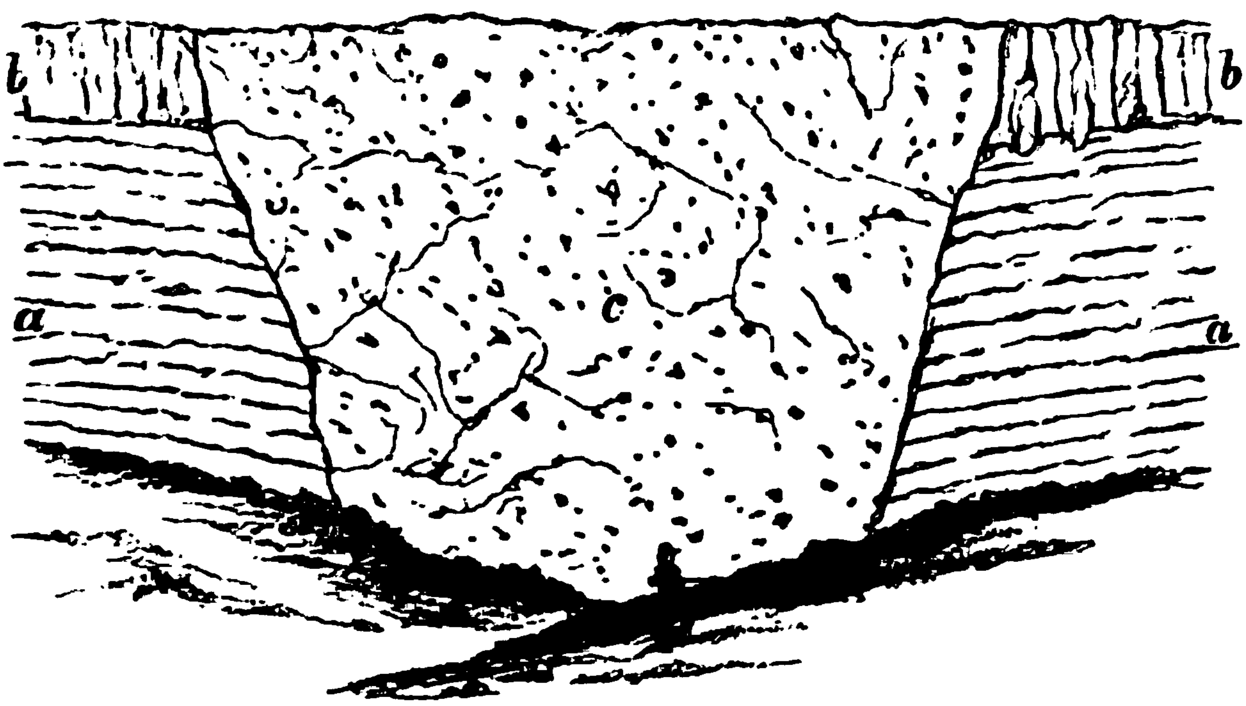

Fig. 107.

Section of neck of agglomerate. Cliff between Portrush and Giant's Causeway.

so as to look on the ground-plan like veins. Another neck is shown in section on Fig. 107. It was sketched by the writer during an ex-

* For descriptions of volcanic necks see *Geol. Mag.*, vol. iii. p. 243; *Memoirs of Geol. Survey*, Scotland, sheet 33, pp. 43, 44; sheet 14, p. 22.

cursion with Mr. Jukes along the coast of Antrim, and occurs on the line of cliff between Portrush and the Giant's Causeway. A cavity, measuring about fifty yards across at the top, has been blown through the chalk (*a*), and also through a previously erupted sheet of basalt (*b*); and this cavity, after perhaps serving as an orifice for the discharge of some of the tuffs of the district, was finally filled up with a coarse mass of rubbish, consisting of blocks of basalt, chalk, etc., imbedded in a dirty green gritty trappean paste.

Though necks are of course intrusive and subsequent, in relation to the rocks which they traverse, they lead us by a natural transition to the consideration of the interbedded and contemporaneous series. Each of them represents the site of an old volcano, and the materials of which it consists remain as evidence of the nature of the volcanic products which were ejected to the surface. To the consideration of these surface products we now proceed.

II. INTERBEDDED OR CONTEMPORANEOUS.

In the foregoing section of this chapter we have had under consideration the petrological characters of those trappean rocks which have been erupted and consolidated at a greater or less depth beneath the surface. Some of these may have had no connection with volcanic action, others were undoubtedly associated with that action. We have now to examine the modes of occurrence of those trappean rocks which were not only connected with the operation of volcanoes, but were actually erupted to the surface as volcanic products.

In the first place, let us inquire on what evidence the interbedded or contemporaneous character is made out. This evidence is based not on the lithological nature of the rocks, for, as already remarked, all rocks which are interbedded must be upward prolongations of those which are intrusive—the same rock, as dolerite, basalt, or melaphyre, being found equally under both aspects. The leading petrological distinctions of the present series are three:—1st. The slaggy character of the upper and lower surfaces of the sheets; 2d. The unaltered character of the overlying beds, and the absence of any derangement of them by, or of veins from, the trap-rock below; 3d. The association of beds of trap-tuff. The value of these characters will be apparent in the succeeding pages.

The species of trap which occur in the interbedded form are not so numerous as those which are intrusive. All the doleritic rocks, melaphyre, diabase, porphyrite, and felstone, are found in the former character. But diorite, quartziferous porphyry, and hypersthene-rock (when not metamorphic), do not appear to occur except intrusively. All these rocks belong to the crystalline division of the trappean series. Of the fragmental division all the varieties of course occur in the interbedded

or contemporaneous form, which is their proper and normal character, the intrusive necks of agglomerate already described being, although important, yet subordinate modes of occurrence.

a. CRYSTALLINE.

When a mass of trap-rock has originally been poured out at the surface in a melted state, it has assumed the character of a lava-flow, and its structure is therefore best understood when compared with that of recent lava. The student is referred to the chapter of this Manual on volcanic action for information on this subject. A sheet of such rock may occur singly, overlaid and underlaid with ordinary sedimentary materials, or it may form only one of a thick series of similar beds, with little or no interstratified aqueous rocks. In either case each single sheet indicates the result of a distinct eruption, or, in other words, is a separate "flow."

As yet we have no very satisfactory method of determining whether a flow has been poured out on the land or under the sea. Of course where one is met with among marine strata we cannot doubt that it is then a submarine lava; or when we find one interstratified with fluviatile or lacustrine deposits, or lying upon an old soil or terrestrial surface, we recognise it as the product of a subaerial eruption. But, apart from such collateral evidence, there does not seem at present to be any trustworthy mode of settling the question from the structure of the flow itself. Where the surface of a bed is very rough and slaggy, like that of a recent *coulée*, we may suspect a subaerial origin; where, on the other hand, the surface, though still perhaps highly vesicular, is not so broken and uneven, we may infer a subaqueous eruption. As a matter of fact, there can be no doubt that the great majority of interbedded igneous rocks met with in the earth's crust have been erupted under water.

Structure of Flows.—The structure of a "flow" is very commonly found to be as follows:—The central part of the sheet is a crystalline, often amygdaloidal mass, more or less compact, sometimes columnar; the upper and lower surfaces consist of rougher slag-like portions, the amygdaloidal cavities being there larger and more numerous, and drawn out irregularly, more especially along the upper surface (see Fig. 108). This structure, it will be noticed, is very distinct from the ordinary aspect presented by an intrusive sheet, where the upper and under surfaces are the most compact, instead of being the most rough, open, and vesicular. It is not always so strongly marked, and there occasionally occurs an example where it is not easy to decide merely from the structure of the mass whether it is to be considered as interbedded or intrusive. This is more especially the case in interbedded sheets, which have undoubtedly been erupted under water; these have a tolerably smooth

upper surface, with sometimes little or no slaggy character.* These slaggy upper and lower surfaces are characteristic of modern lavas, and their occurrence among trap-rocks indicates the interbedded or contemporaneous relations of the masses by which they are exhibited.

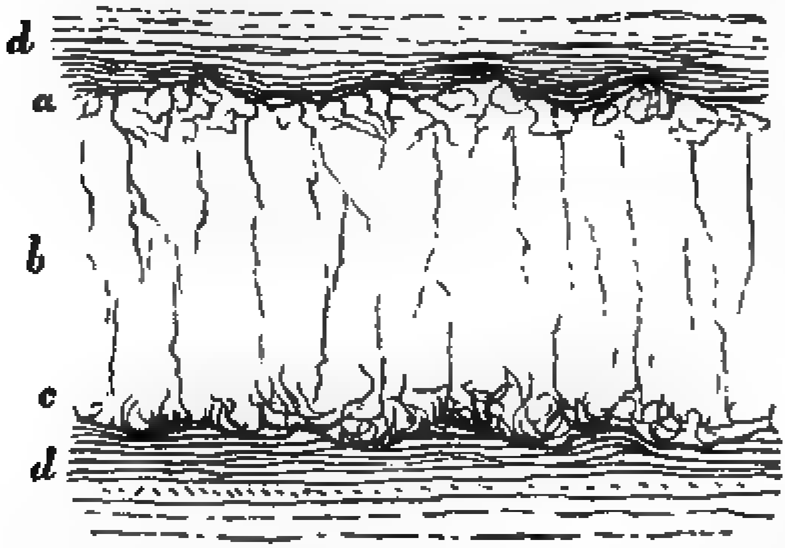

Fig. 108.

Section of an interbedded or contemporaneous sheet.

a. Slaggy upper surface ; *b.* compact central portion ; *c.* slaggy lower surface ; *d d.* strata of sandstone, shale, trap-tuff, or any other sedimentary materials.

Another feature common to interbedded sheets, whether they occur singly or in a thick series, is a jointed structure. In some cases the joints are very irregular ; usually, however, they are well marked in two or more sets, which cross each other and extend perpendicularly to the upper and lower surfaces of the sheet. These joints, when they occur with some regularity, give a prismatic structure to the rock, which increases in symmetry until it passes into the perfectly columnar arrangement, as in the dolerite of the Isle of Staffa and the Giant's Causeway. Occasionally the columns are bent, wavy, or even arched. Some beautiful examples of such curved columns may be seen in several parts of the cliffs of Staffa (Fig. 109). It is a common mistake to call this columnar structure *basaltic.* Basalt, indeed, is very often columnar ; but dolerite, diorite, felstone, porphy-

Fig. 109.

Curved dolerite columns. Clam-Shell Cave, Staffa.

From a Photograph.

* I was much struck with this feature in the basalt sheets of Gergovia in Auvergne. These seem to have been poured over the old Tertiary lake-bottom of the Limagne d'Auvergne, and their upper surface recalled that of an intrusive sheet rather than an interbedded flow.

rite, and pitchstone, also exhibit the same structure. The columns always spring from the upper and lower surfaces of the bed, that is, from the original surfaces of cooling, and when they are bent they indicate a slight additional movement of the still viscid mass after they were formed, or while they were forming.

Reference has already been made to the amygdaloidal texture of interbedded trap-rocks. This is one of their characteristic though not peculiar features. When amygdaloidal sheets are carefully examined, they often show that the vesicles in which the amygdaloidal kernels are contained are elongated in a particular direction, especially along the top of the bed. These vesicles were formed by the expansion of steam imprisoned within the melted rock at the time of its emission, and their elongation shows the line along which the rock, while still uncongealed, was moving.

Relation of a Flow to its Overlying Stratified Rocks.—When a flow or sheet of interbedded trap-rock occurs singly among stratified deposits it presents features distinct from those which mark the occurrence of an intrusive sheet. The strata underneath it are not usually caught into it in angular projections and fragments, nor is the line of demarcation between the igneous and aqueous rock a sharp and even one. The lower surface of the trap is almost always more or less uneven (see Fig. 108), and the underlying stratum fills up the hollows or wraps round the projections of the trap in such a way as we might anticipate would happen where a heavy mass of melted rock rolled over a floor of only partially consolidated sediment. Sometimes the strata below the trap are hardened, sometimes they do not seem to have suffered at all. The strata overlying the igneous rock afford evidence of having been laid down upon that rock, and not of having been displaced by its intrusion below them. (See Fig. 110.) They are not altered. They fill in all the irregularities

Fig. 110. (Jukes.)
S. Stratified rock, the lamination of which conforms to the rugged surface of T, a trap, in such a way as to show that it was deposited upon it.

of the trap, and in many cases contain little grains or pebbles of it. Instances occur where the trap in cooling has cracked, and where the cracks have subsequently been filled up by the sediment which was

gathering over the hardened flow (Fig. 111). The sediment in such case is stratified horizontally, and even shows false-bedding, so that at first

Fig. 111.
Cracks in an interbedded porphyrite flow, filled in with sandstone from above. Old Red Sandstone. Turnberry coast, Ayrshire.

sight the vertical "dykes" (so to speak) of sandstone, look like pieces of a broken sandstone stratum involved in the trap. It is only when a series of them is seen that they are found to occupy rude star-shaped cracks of the igneous rock, to be all stratified in the same general plane as the strata above and below, and to show that they could only have been washed in originally before the strata overlying the trap were laid down.*

Sometimes we meet with a single sheet of interbedded trap intercalated among ordinary sedimentary strata, and with no other igneous rock for some distance either in the series of strata below or in that above it. Such solitary sheets are exceptional. Some good examples occur in the coalfield of Borrowstounness, where independent sheets of doleritic trap are intercalated among the coal-bearing strata. These sheets vary from 4 to 265 feet in thickness. In one coal-pit a total thickness of 391 feet of crystalline trap-rock was passed through, between and below which the coal-seams were found to be quite unaltered.†

Consecutive Groups of Flows.—In most cases, however, the sheets do not occur singly. They are found usually in a series—sometimes a few together, with stratified layers between; sometimes in a great succession of sheets, as in the volcanic plateaux of Antrim and the Inner Hebrides; sometimes in frequent alternations with sheets of trap-tuff and trappean conglomerate, as in the Old Red Sandstone of Central Scotland. When contemporaneous sheets are piled over each other in a thick series, as in Antrim and the Inner Hebrides, they often present great differences of texture, even though they may all belong petrographically to the same variety of rock. This alternation of texture makes their bedded character very apparent even at a distance. Over a columnar bed, for example, will come a rough amorphous amygdaloidal

* I found many admirable examples of this kind among the porphyrites imbedded in the Middle Old Red Sandstone series of the south of Ayrshire.

† *Mem. Geol. Surv.*—Geol. of Edinburgh, chap. vii.

one; then one which from jointing weathers in clean vertical faces; then one made up of curved starch-like prisms; then another columnar one, and so on. Sometimes the bedded form is further distinguished by great differences of colour among the beds, or by the interstratification of one or more beds of tuff. The subjoined section (Fig. 112) repre-

Fig. 112.
Alternation of beds. Staffa.
a. Prismatic basalt; b. trap-tuff; c. columnar basalt; d. prismatic and amorphous basalt; e. columnar basalt.

sents part of the south-west cliff of the Island of Staffa. The lowest bed is seen on detached skerries as a prismatic basalt (*a*); next comes a basalt-tuff (*b*), then the well-known and beautifully columnar basalt (*c*), in which Fingal's Cave has been excavated. This is succeeded by other beds (*d*), some rough and amorphous, others confusedly prismatic. Lines of vesicular or scoriaceous texture are often found dividing tolerably compact trap, and they may usually be taken as indicative of lines of division between different flows—the rough vesicular top of one sheet being covered by the similarly rough and vesicular bottom of the next sheet, so as to form a vesicular zone between two compact beds. That one great sheet of trap may be in reality made up of different flows, and that some care is required before any decision on this point may be justified, is further shown by the fact that a mass of trap, which at one place might be supposed to be the result of a single eruption, is found a little further on to be split up by the intercalation of some stratified layers (tuff, sandstone, shale, etc.), which perhaps increase in thickness till the severed sheets of the trap are some yards apart. This is not to be confounded with the way in which intrusive sheets come together or split up, so as to enclose tapering wedge-shaped masses or sheets of stratified rock. In the latter case, as we have seen, the strata are altered or broken across, while, in the former, the nature of the wedge of

stratified beds, as well as the upper and under surfaces of the trap, show the contemporaneous character of the whole series.*

Hill-ranges of Contemporaneous Crystalline Trap-rocks.—When a thick group of felstones, porphyrites, or other crystalline rocks, is interbedded in any formation, and inclined with the other members of that formation, its line of outcrop is marked by a range of rounded or conical hills, often with lines of sharp escarpment. Such is the nature of the ground where the igneous rocks are intercalated in the Lower Silurian system of North Wales, and partake in all the plications and dislocations of the sedimentary rocks. In the Old Red Sandstone series of Scotland, in like manner, the contemporaneous sheets of porphyrite form important hill-ranges, as the Ochils, Sidlaws, and Pentlands. In all these large masses of crystalline rock there are usually intercalations, sometimes on a great scale, of trap-tuff and trappean sandstone and conglomerate.

Plateaux.—Where a great series of consecutive sheets of contemporaneous crystalline trap-rocks, instead of being inclined to the horizon, lie flat or nearly so, they give rise to the formation of plateaux. The edges of these elevated tracts are sometimes lines of precipice or steep escarpment, and sometimes terraced slopes, the terraces being singularly regular and formed by the edges or outcrops of the harder sheets of trap. We have many admirable examples of these forms of ground in the great tertiary basaltic district which extends through Antrim and the islands of the Inner Hebrides, also in the carboniferous porphyrites of the Campsie, Kilpatrick, Renfrewshire, and North Ayrshire hills. On a much grander scale are the terraced trappean plateaux of Abyssinia, Western India,† Victoria,‡ and many other regions.

β. FRAGMENTAL.

Under this division are included all the varieties of trap-tuff, whether fine grained, and in that state often called "ash," or coarse grained, and then often undistinguishable from trap-conglomerate. These various fragmental rocks are to be regarded as the consolidated detritus ejected by former volcanoes either on the land or under water.

Lithological Varieties.—Trap-tuff is a generic term. It includes tuffs derived from all those crystalline trap-rocks which occur in the interbedded form, but not from those which only appear as intrusive masses. The reason for this arrangement is obvious. The tuffs are all

* The well-known toadstone of Derbyshire, according to Mr. Jukes, affords examples of the union in some places of flows, which in other places are separated by intercalated strata.

† See Mr. Blandford's *Geological Report of the Abyssinian Expedition*; also his *Memoir on the Traps of Western India*.

‡ See *Reports of the Geological Survey of Victoria*, by Mr. Selwyn.

surface ejections, formed by the explosion of melted trap-rock which rose in volcanic vents. Consequently only those varieties of crystalline trap which have been directly the products of volcanic action have given rise to tuffs. The deep-seated or so-called Plutonic trap-rocks have not furnished tuffs. Hence, too, while tuffs may be, and very commonly are, intimately associated with contemporaneous crystalline traps, they are not so connected with the intrusive forms. Intrusive masses do indeed traverse trap-tuffs often enough; but this is merely an accident, and no more indicates a relation between the intrusive rock and the tuff than does the piercing of sandstone or limestone by similar intrusive rocks.

All the varieties of crystalline trap-rock, therefore, which occur as interbedded sheets may be associated with tuff originally derived from the explosion and trituration of their substance. Felstone, porphyrite, melaphyre, and diabase, have each their tuffs. We find, too, that the nature and distribution of the tuffs are regulated by those of the crystalline interbedded traps. In a felstone district, for instance, the tuffs are felstone-tuffs derived from the volcanic destruction of felstone. In a region where melaphyre prevails the tuffs are melaphyre-tuffs (greenstone-tuff). As a rule, we do not find any mingling of the tuffs unless there happens also to be an association of different forms of crystalline trap. Porphyrite and melaphyre, for example, are found together in the west of Scotland, and there the fragmental forms are both melaphyre-tuffs and porphyrite-tuffs, or sometimes intermediate varieties, formed by the intermingling of the two in different proportions.

The tuffs of the felspathic series of trap-rocks are well defined from those of the augitic series. There seems to be no certain rule, however, to distinguish a tuff of felstone detritus from one of porphyrite; while in the same way the tuffs derived from the different varieties of augitic trap cannot always be discriminated from each other. The latter receive the general name of Greenstone-tuff from some petrographers.

While trap-tuff consists fundamentally of comminuted trappean detritus, it is often mingled with a varying proportion of ordinary sedimentary detritus. If we reflect that in many cases the materials of the tuff fell into water, at the bottom of which sand, mud, or lime was gathering at the time, we perceive that the result must often have been a mingled mass of sandy, clayey, or calcareous tuff, or of tuffaceous or ashy sandstone, shale, or limestone. Hence, as trap-tuff is a mechanical mixture, we must not expect in its varieties the same general uniformity of composition as among the crystalline trap-rocks.

Varieties of Texture and Structure.—The same reasons which lead us to look for no great uniformity of composition among the varieties of trap-tuff suffice to account for the great irregularities in the texture and

structural arrangements of these rocks. Sometimes the tuffs consist of an exceedingly fine sand or powder, which, on examination, proves to be that of felstone, porphyrite, melaphyre, or some other variety of the interbedded crystalline trap-rocks. Such fine-grained tuffs often show no laminæ and no very well-marked or frequent lines of stratification. At other times they are divided by layers of coarser texture, or by lines of detached stones. Tuffs frequently consist of a kind of compacted gravel, composed of small, rounded, or angular fragments or *lapilli* of different kinds of crystalline trap, usually more or less decomposed. Layers of this kind often alternate with others of a finer texture in rapid succession, indicating the changing character of the showers of dust and detritus shot out by the old volcano. Again, the trap fragments increase in size until the rock resembles coarse conglomerate or breccia. Among the fragments are usually found pieces of the rocks underneath, such as shale, sandstone, limestone, etc. These are frequently quite angular, and sometimes of considerable size.

Ejected Blocks in Tuff and other Strata.—Occasionally blocks are found in tuff which consist not of one variety of rock but of a number of strata which had been shattered by the volcanic explosion, and of which the disjointed fragments are now enveloped in the tuff. Some remarkable examples of this kind occur in the greenstone-tuff at Niddry Castle, Linlithgowshire. One of these (marked *b*, in Fig. 113) is a large fragment torn off from an alternation of shales

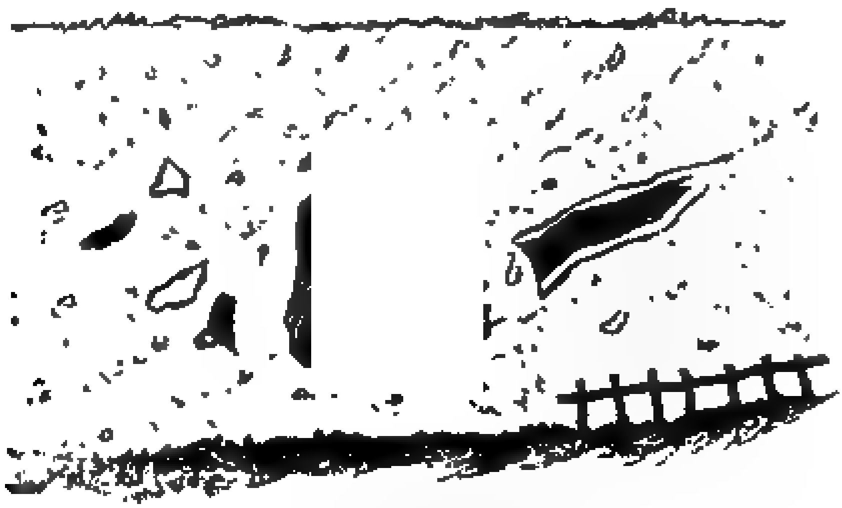

Fig. 113.
Ejected blocks, consisting of shale (*a*), and shale with limestone (*b*), in the greenstone-tuff of Niddry, Linlithgowshire.

with bands of a ferruginous limestone, locally known as cement-stone, the strata being still affixed to each other. Ejected blocks are of course most abundant in the coarser forms of tuff. But they occur also now and then even in the finest-grained varieties, and their pre-

sence there is a strong proof of the volcanic origin of these deposits. Had these fine tuffs been due merely to the transporting power of currents of water, laden with fine sediment in suspension, there should not have been any large stones in them, for the current which could carry along such stones would have been too powerful to admit of the deposition of fine sediment at the bottom.* Hence the stones are to be regarded as blocks, or sometimes as bombs, which have been ejected from some volcanic orifice at the time of the eruption of the finer materials of the tuff. But extraneous volcanically-derived blocks are not confined to the tuffs; they occur also even in the ordinary sedimentary strata intercalated in a trappean series. An interesting example was described by the writer some years ago from the district of Burntisland, Fifeshire. Between two beds of melaphyre a series of strata is there interposed to a thickness of about thirteen feet, consisting of shales, fireclay, sandstone, and a thin coal-seam. In this group of beds there occurred the section shown in Fig. 114. It will be seen that the coal-seam in that figure has been squeezed by the fall of the stone upon it; also, that the layers of the lower half of the green crumbling clay above the coal are bent down round the stone, while those of the upper half rise up to it, and finally cover it in an unbroken line. It is clear that this stone must have fallen from above, and with some force, so as to bend down and compress the soft mud and the partially consolidated layer of vegetable matter, and the abundance of melaphyre, tuff, and other volcanic products at the locality, leaves us no room to doubt that the stone was originally ejected from a volcanic orifice. The date of its flight and fall is accurately fixed, for the stratification of the clay shows us that the event took place just when the clay-bed was half deposited.†

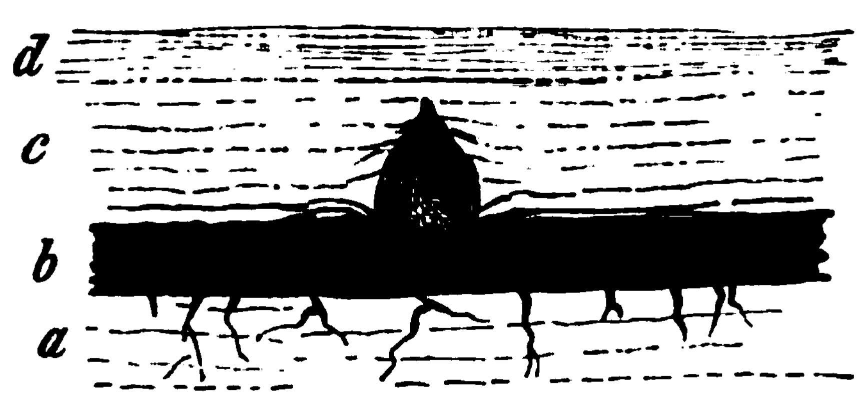

Fig. 114.

Ejected block of melaphyre. Burntisland, Fife.

a. Fireclay, with rootlets; b. coal-seam, 5 or 6 inches, with melaphyre block resting on it; c. fireclay, 1 foot; d. shale (with plants, etc.) becoming mixed with trap-tuff towards the top.

For the sake of illustration two additional examples are given from modern volcanic districts, which the present writer observed after he had described the foregoing case from Fife. In one of these

* In rare cases we find in fine aqueous deposits stones which may have been carried by roots of trees or by floating ice. (See *ante*, p. 184.) They could only have had an extraneous origin.

† Geikie, *Geol. Mag.* i. p. 24.

(Fig. 115), from the volcanic island of Lipari, a block of obsidian shows by its position, and the way in which the layers of tuff are bent down around it, that it was ejected when about half the thickness of the part of the tuff shown in the sketch had been thrown down. In the other case (Fig. 116), from one of the old tuffs of Vesuvius, a block of leucitic lava about five or six pounds in weight bore testimony in the same manner to the exact period in the history of the tuff at which it was discharged from the crater.

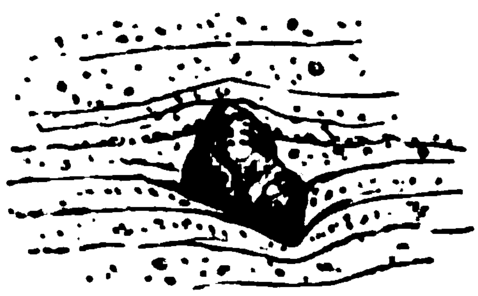

Fig. 115.
Ejected stone in trachyte-tuff. Island of Lipari.

Fig. 116.
Ejected block in old tuff of Vesuvius, a little below the Hermitage.

Among the blocks found in trap-tuff some are occasionally met with which are round and of a slag-like character. Sometimes the vesicles of such ancient slags are pulled round the outside of the ball, now and then the balls are hollow or partially filled with loose earth. Such blocks are called bombs, and are regarded as having been thrown off in a melted state from a surface of ebullient lava.

Among the contents of trap-tuff are sometimes found crystals of different minerals, which have been originally erupted along with the other loose materials of the tuff.* They give a pseudo-porphyritic aspect to the tuff. On examination, however, such crystals (felspar, augite, etc.) will be found usually more or less injured, rounded, or broken, though sometimes perfect, like the perfect crystals of augite in the old tuffs of Monte Somma.

It is not uncommon among the greenstone tuffs of Scotland to meet with angular chips and fragments of fossil-wood, which on microscopic examination proves to be of coniferous character. Such fragments are not uncommon in the tuff of Largo, Fifeshire, and they occur abundantly in that of St. Magdalens, Linlithgow. They are not found along with other parts of a previous fossiliferous stratum, which might be supposed to have been shattered into fragments by a volcanic explosion. On the contrary, they are sometimes found where no piece of sandstone or other ordinary aqueous rock is to be seen, and in such a way as to suggest that they are original fossils in the tuff. It is not easy, however, to account for their chip-like angular character.† They are not to be confounded with the plant-remains sometimes found in considerable abundance deposited regularly in tuff, as in sandstone and shale, to which reference will be immediately made.

* See Ramsay's Memoirs on N. Wales—*Mem. Geol. Surv.*, iii., p. 31.

† I have noticed similar fragments of lignite in the trass of the Brohl Thal.

Occasional Fossiliferous Character of Trap-tuff.—We have seen that where the materials of tuff have fallen on localities where ordinary sand or mud, or other sediment, was accumulating at the time, the tuff has necessarily become intermingled with those sedimentary deposits. In like manner, if the volcanic dust and stones fell on places where plants or animals were living, or where their remains were being gathered together, the tuff there formed would entomb and preserve these organic remains, and thus become *fossiliferous*. This has in effect happened very frequently in geological history. The massive tuffs of the Lower Silurian system of Wales often contain crinoidal, molluscan, crustacean, or other organic remains, and sometimes in such abundance as to pass into a kind of impure limestone. The tuffs of the Carboniferous system of the Lothians sometimes contain in well-preserved specimens the ferns, calamites, sigillariæ, and other characteristic plants of that formation. In the same region, too, we sometimes see how the corals, crinoids, and shells of the Carboniferous limestones were killed on the sea-bottom by showers of tuff, and how their survivors again spread themselves over the new floor of tuff, and lived and died for generations, forming by their accumulated remains a fresh bed of limestone, until anew interrupted by other volcanic discharges.

Passage of Trap-tuff into other Rocks.—From what has now been said it will be seen that tuff may readily pass into sandstone, clay, shale, limestone, or other sedimentary rock. This happens both vertically and horizontally. If the materials of a bed of tuff began at first to be erupted very gently, and fell on a bottom where sand was accumulating, there would first be a gradual mingling of the sand and tuff: if the discharges became more copious and abundant the sand would cease to be traceable, and a bed of tuff would cover it; while, if the final showers diminished gradually, there would be a second mingling of the materials of this tuff with the ordinary sediment. In this way, if we examined a section of the deposits, we should find that a sandstone passed up into a tuff, and that the tuff passed up into sandstone, shale, or other aqueous rock. Similarly, at the extreme limits of any shower of volcanic detritus there would be a mingling of that detritus with the contemporary sediments, so that when we can trace the horizontal extension of a bed of tuff we may naturally expect to find it passing into some other sedimentary rock—the place where the passage takes place indicating the limit to which the volcanic shower reached in one direction.

The student, in the course of his reading, especially among the earlier treatises on geology, will often meet with statements that tuff passes into basalt, melaphyre, or other variety of crystalline trap. All such statements, in so far as they imply an original passage of the one rock into the other, are erroneous, and proceed from ignorance of the

true nature and distinction of crystalline and fragmental igneous rocks. It might with equal truth be said that a coulée of molten lava passes into the loose ash which is simultaneously ejected. The error seems to have arisen from a want of recognition of the effects of decomposition or "weathering." All rocks are subject to decay when exposed to the atmosphere, and none more so than trap-rocks. Some of the most solid and crystalline varieties waste away into a mere sand. In such cases (and this happens characteristically with the doleritic group), the rock often weathers into globular masses, the centres of which are still hard when all around them has decayed. These hard cores, scattered through the soft tuff-like mass, are sometimes sufficiently like ejected blocks to deceive an unwary observer, who, if he found the decomposed rock passing into good crystalline-trap, would very naturally conclude that he had met with an instance of the passage of trap-tuff into dolerite. Sometimes, too, the rocks along the line of junction of a tuff with a crystalline trap are so decayed that the separation of them cannot be very sharply made. But this is a very different thing from a statement which implies that tuff and crystalline trap originally passed into each other.

Alteration of Tuff.—Much difficulty is sometimes experienced in separating out the trap-tuff from the crystalline rocks in districts where all the rocks have undergone some metamorphism, or where they have been affected by slaty cleavage. Still greater perplexity attends the attempt to ascertain in such cases the original petrographical characters of the tuffs apart from those subsequently acquired from metamorphism. Thus, in the Snowdon district, says Professor Ramsay, so completely has slaty cleavage affected both felstone and tuff, that there is sometimes the utmost difficulty in drawing a line of demarcation between the two.* Mr. Jukes and his colleagues of the Irish Geological Survey have met with similar features in the County Waterford.

γ. EXAMPLES OF THE MODE OF OCCURRENCE OF THE CONTEMPORANEOUS OR INTERBEDDED TRAP-ROCKS.

It would extend too much the space which can here be devoted to the description of the trap-rocks, to give illustrations from different localities of the various modes in which the student may expect to meet with these rocks. In the subsequent part of this Manual, however, where the geological formations are described, a succinct notice will be given of the volcanic phenomena presented by each of the formations in the United Kingdom. In the meantime the student may take note that he will find examples of the association of vast flows of felstone and thick deposits of tuff over an extensive area, described in the chapter on the Lower Silurian rocks; of the local emission of pyroxenic crystalline

* *Memoir on N. Wales*, p. 120.

rocks and tuffs over limited areas, and of the local abundance of tuff-cones in the narrative given of the Carboniferous system; of the occurrence of volcanic necks with connected melaphyres and tuffs in the Permian chapter; and of the accumulation of enormous piles of basalt-flows, with little ejection of tuff, in the account of the British miocene rocks.

8. DISTRIBUTION OF CONTEMPORANEOUS TRAP-ROCKS IN SPACE AND TIME.

If we look at a map of the active volcanoes of the globe, we find that their distribution is far from regular and uniform. On the contrary, while the volcanoes tend to group themselves along far-extended lines, they are crowded together in some regions, very sparsely placed in others, while over many areas of wide extent they are altogether absent. This will be further alluded to in a subsequent chapter. It is now referred to by way of illustration and explanation of the fact that the interbedded trap-rocks, which, as we have seen, are only ancient volcanic rocks, exhibit a similar local and irregular distribution. In some countries they are remarkably abundant, in others they do not occur at all. Further, inasmuch as the crust of the earth has been found to consist of a number of "rock-formations" belonging to successive periods of the earth's history, so we discover that the trap-rocks occur in all these formations, in other words, that volcanic rocks have been produced in all ages of the world's existence, as far back as purely geological evidence leads us. Hence we are enabled to trace the distribution of volcanic action over the globe in regard both to time and to space. We may either take any one formation or system—such, for example, as the Carboniferous—follow its extension over the globe, and mark where it furnishes proofs of contemporaneous volcanic phenomena; or we may choose some particular district of country, and set ourselves to the task of discovering what traces of such phenomena it contains in its different rock-formations. In the former case we are led to inquire into the development of volcanic action over the globe at a particular period of the past; in the latter we try to follow the history of that action in one region from the remotest period down to recent times.

There seems to have been considerable uniformity in the leading features of volcanic action during the past history of the earth. The tuffs and melaphyres found among our carboniferous rocks occur very much as modern tuffs and lavas do. The ancient rocks, crystalline and fragmental, are interbedded with each other, or with sedimentary deposits, just as lavas and ashes are now piled over each other by the eruptions of an active volcano. Yet a rigorous and minute comparison of the two would perhaps bring to light a number of distinctions.

A greater diversity exists, however, in the mineralogical nature of the products which volcanic action has brought to the surface. The modern lavas of Vesuvius or Hecla are very different, lithologically,

from the diabases and melaphyres of our palæozoic rocks, and the trachytes of the Rhine from the felstones of Wales. To what causes this difference is due remains one of the problems of geology. It has been suggested that the crust of the earth, on solidification, contained two layers or coatings—an inner one, composed mainly of the heavy or basic rocks, and an outer one, consisting chiefly of the lighter or acidic rocks.* The older rocks appearing at the surface would thus be siliceous, such as the felstones, etc., while those from the inner "magma" would only appear at a later period, and would be of the pyroxenic varieties, such as basalt, etc. Certainly it is the fact that the oldest interbedded volcanic rocks are felspathic and highly silicated, while the great mass of modern lavas is pyroxenic. Yet it is equally true that many of the palæozoic lavas are heavy and pyroxenic, while the light and siliceous lavas, trachyte and obsidian, are common enough among tertiary and recent volcanic products.

This is a subject in which comparatively little has been accomplished. Yet it is one so full of interest that it will probably ere long attract much more notice than it has hitherto received. By way of indicating the nature of the kind of research which must be undertaken, it may not be without use to take as an illustration the volcanic geology of the British Isles, and to add here a few remarks upon it for the guidance of the student.

Volcanic or Contemporaneous Trappean Rocks of Britain.†—In succeeding chapters a brief description will be given of the igneous rocks associated with each of the British formations. At present, therefore, it will suffice to remark that volcanic action was abundant and prolonged during the lower Silurian period in Wales, in the Lake district, and in the south-east of Ireland; that it was manifested during the upper Silurian period in the south-west of Ireland; during the times of the Old Red Sandstone abundantly in Scotland; in the Carboniferous period in the midland valley of Scotland, in Limerick and in Derbyshire; in the Permian epoch in the south-west of Scotland; in the New Red Sandstone in Devonshire; and during the Tertiary period, on an enormous scale, from the north of England and the south of Antrim northwards through the Inner Hebrides to the Faroe Islands, and even to Iceland. Hence within so limited an area as the British Islands we have an extensive series of old volcanic rocks, ranging from Lower Silurian down to Tertiary times.

But not only has volcanic action been remarkably continuous in Britain when the whole range of geological history is considered. We find that this continuity has been exhibited even in small isolated portions of our area. "Take, as an illustration, the neighbourhood of Edinburgh within a radius of ten miles from the town. First and oldest comes the long range of the Pentland and Braid Hills, consisting of a mass of bedded igneous rocks in a middle series of the Old Red Sandstone. These old lavas reach a thickness of 4000 or 5000 feet. Next in chronological order are the Calton Hill and lower portion of Arthur's Seat, which mark the continuance of volcanic action (though in a lessened degree) into the

* See the "Essay on Comparative Petrology," by Durocher, translated by Dr. Haughton, and appended to his *Manual of Geology*.

† Presidential Address to Brit. Assoc. 1867. Dundee.

lower Carboniferous period. The Carboniferous rocks for miles around these hills are full of the traces of contemporaneous volcanoes, sometimes in the form of sheets of tuff marking the occurrence of little detached tuff-cones, sometimes in wider areas of tuff, basalt, and dolerite, where a group of minor volcanic vents threw out showers of ash and streams of lava. To the east rise the isolated Garlton Hills, which date from before the Carboniferous Limestone; westwards, scores of little basaltic crags and rounded tuff-hills mark out the lower Carboniferous volcanoes of Linlithgowshire. To the north the endless crags, hills, and hillocks of the Fife coast contain the record of many eruptions from the middle of the Calciferous Sandstones high up into the Carboniferous Limestone group. Even the Coal-measures of that county are pierced with intrusive bosses of trappean agglomerate, which indicate the position of volcanic vents, possibly of Permian age. The same, or a more recent date, must be assigned to the later unconformable agglomerate and basalt of Arthur's Seat. Nor is this the whole. Latest of all come innumerable trap-dykes, running with a prevalent east and west trend, and cutting through all the other rocks. These may, with probability, be assigned to a Tertiary age. Here, then, in this little tract, about the size of a small English county, there are the chronicles of a long series of volcanic eruptions, beginning in the middle of the Old Red Sandstone, and coming down to a time relatively so near our own as that of the Miocene rocks. Nor is this by any means an exceptional district. Illustrations of a similar persistence of volcanic action may be gathered in many other tracts of equally limited extent."

"It may be possible eventually to arrive at some approximate realisation of the form assumed by the surface of the country during successive phases of volcanic action. There are indeed indications that the eruptions were apt to occur along lines of broad valley. The long depression, for instance, between the Highlands and Southern Uplands of Scotland, continued to be the site of active volcanoes during the Old Red Sandstone and Carboniferous periods; yet the high grounds on either side seem to have in great measure escaped, for few of the trap-beds or of the 'necks' marking the points of eruption, have as yet been detected there. Again, the Tertiary basalts of the north-west lie in a long hollow (at least as old as the Lias) scooped out of the metamorphosed Silurian and Laurentian rocks. In these instances it is evident that the numerous volcanic orifices were grouped linear-wise."

"This leads me to remark that a study of the igneous rocks of Britain furnishes no proofs that volcanic action has been slowly diminishing in intensity during past geological time. The amount of volcanic material preserved in our Old Red Sandstone group probably exceeds that of our Silurian system, even after all due allowance for the denudation of the older formation. The number of distinct volcanic centres traceable among the Carboniferous rocks in like manner surpasses that of the older formations. But by much the most extensive mass of volcanic material in these islands belongs to the latest epoch of eruption—that of the Miocene period. In one mountain alone, Ben More in Mull, these youngest lavas rise over each other, tier above tier, to a height of more than 3000 feet; yet their base is concealed under the sea, and their top has been removed by denudation. We have here, therefore, no proof of a slow diminution of volcanic activity. The period separating the Miocene basalts from the New Red Sandstone traprocks, which seem to come next to them in point of recentness, was immensely vaster than that which has elapsed between the Miocene basalts and the present time. There is thus no improbability in the eventual outbreak once more of the subterranean forces. Nay, further, were a renewed series of volcanic eruptions to take place now, they might in the far distant future be thrown together with those of Miocene date, as proofs of one long period of interrupted volcanic activity, just as we now group the igneous rocks of the Lower Silurian, or of any other geological formation. So near to us, in a geological sense, are those latest and grandest of our volcanic phenomena."

"Another fact, which a general survey of the character of our volcanic rocks soon brings before us, is, that as a whole those of earlier date differ distinctively in composition from those of more recent origin. From the first traces of volcanic activity in this country up to about the close of the Old Red Sandstone or beginning of the Carboniferous series, the interbedded (that is, contemporaneous) igneous rocks consist for the most part of highly felspathic masses, to which the names of clinkstone, claystone, compact felspar, porphyry, felstone, porphyrite, etc., have been given. In most of these rocks there is an excess of silica (55 to 80 per cent), which is sometimes found separated out into distinct granules. On the other hand, from the upper part of the Old Red Sandstone, or the lower members of the Carboniferous series, up to the end of the long history, the erupted masses are chiefly augitic, as basalts and dolerites (including melaphyres and diabases). In these rocks free silica is not a normal constituent, while the alkalies, alkaline earths, and metallic oxides, form on an average about half of the whole mass. In the former class the acid element predominates, in the latter the bases are specially conspicuous. Were these rocks subjected to further and more detailed chemical examination, additional knowledge might possibly be acquired respecting the history of the changes which have taken place within the crust of the earth."

In the subjoined Table a first attempt is made to group the interbedded traprocks of Britain chronologically, according to their dates of production, and petrographically, according to their mineral characters. So little has yet been done in this country on this subject, that the Table is confessedly very imperfect, and is inserted for the purpose of indicating the kind of arrangement, which may be afterwards elaborated and improved.*

Table of the Stratigraphical Distribution of the British Interbedded Trap-rocks.

Formations.		Crystalline.								Fragmental.		
		Felspathic.				Pyroxenic.						
		Felstone.	Porphyrite.	Pitchstone.	Trachyte?	Diabase.	Dolerite, including Melaphyre.	Basalt.	Tachylite.	Felspathic.	Pyroxenic.	Necks.
Tertiary.	Pliocene	"	"	"	"	"	"	"	"	"	"	"
	Miocene	"	?	+	+	"	+	+	+	?	+	+
	Eocene	"	"	"	"	"	"	"	"	"	"	"
Secondary.	Cretaceous	"	"	"	"	"	"	"	"	"	"	"
	Jurassic	"	"	"	"	"	"	"	"	"	"	"
	Triassic	"	"	"	"	"	+	"	"	"	+	"
Palæozoic.	Permian	"	"	"	"	"	+	"	"	"	+	+
	Carboniferous	"	+	"	"	+	+	+	"	+	+	+
	Old Red Sands.	+	+	"	"	+	?	"	"	+	"	+
	Silurian	+	?	"	"	+	"	"	"	+	"	+
	Cambrian	?	"	"	"	"	"	"	"	"	"	"
	Laurentian	"	"	"	"	"	"	"	"	"	"	"

* The fatal error of such Tables as that of Senft (*Classification der Felsarten*, Tab. I.) is, that no distinction is made between intrusive and interbedded rocks—an error which, for almost

"As geologists, it is important for us to note that, though two classes of volcanic rocks can be determined by analysis of their composition, no broad essential distinctions appear to be traceable in the general mode of occurrence of these rocks. The earlier volcanoes, which threw out siliceous lavas and ashes, seem to have acted very much in the same way as those of later date, which gave out the heavier pyroxenic lavas. Certain minor differences are indeed readily observable. Thus the older lavas occur as a rule in much thicker beds than the later ones, which, indeed, are distinguished by that markedly bedded character which results from the number and thinness of their successive flows. As a concomitant of this arrangement also, columnar structure is much more frequent among the pyroxenic than among the siliceous rocks. Perhaps, if these and other distinctions were collected and compared, each class of rocks might be found to possess certain characteristic peculiarities of its own, sufficient, when taken together, to give us a type for general reference. Nevertheless, in its broader features, there would seem to have been a striking uniformity in volcanic action from the earliest times down to our own day."

"One other part of the subject I would allude to as deserving of inquiry. There seem to me indications that local but well-marked metamorphism and the extravasation of syenitic and granitic rocks have taken place in connection with some of our most recent volcanic phenomena. In Skye, for example, as first pointed out by Macculloch, the Lias limestones are much altered and pierced by masses of syenite, which is in some places a true granite. This crystalline rock must have been erupted after the deposition of the middle Oolitic rocks, for it disrupts and sometimes overlies them. It is manifestly connected with the trappean plateaux and dykes of that region. Southwards in Mull, masses of syenite of a like kind are found in the heart of the great tertiary basalts, and these basalts show there a marked change in texture and aspect, as if they had been more or less metamorphosed. Still farther south lies the granite of Arran, which is, at least in part, of later date than the lower Carboniferous rocks, for these are pierced by it. In and around it, as is well known, there is a profusion of trap-dykes, like those of Skye and Mull. This association of syenite or granite with hundreds of dykes, or with vast piles of basalt, deserves to be worked out carefully in the field. It will doubtless be found to furnish additional data towards elucidating the origin of granite, and even perhaps some portion of the still obscure subject of metamorphism." *

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all geological purposes, renders the Tables valueless. Senft, for instance, represents basalt occurring in the gneiss and schist groups of his "Urperiode," and thence up through the Palæozoic, Secondary, and Tertiary periods. It is of course true that basalt-veins and dykes are found in palæozoic granite, gneiss, and schist; but that is a mere accident, and indicates no geological relationship between the two. The same dyke sometimes traverses half-a-dozen different formations, to all of which it is subsequent, and with which it has no chronological connection. It seems hardly worth while laboriously to chronicle what formations basalt may intersect, for there is no reason why it should not be found in every one which is older than the date of the last emission of basalt. The great object to a geologist is to ascertain at what period any given rock was erupted. Hence, for the reasons already assigned in the text, he must have recourse not to the intrusive but to the interbedded rocks; but the distinction between these two modes of occurrence has never yet been adequately realised and adopted by German geologists. The baneful influences of Wernerianism are not even now wholly dispelled among our German brethren of the hammer. In mineralogy and petrography they are, as a whole, a long way ahead of us, but in the study of the structure and history of rock-masses, particularly of igneous rocks, we are certainly very far in advance of them.

* The remarks quoted above on the British volcanic rocks are taken from the writer's Address to the Geological Section of the British Association in 1867, at Dundee.

CHAPTER XIV.

MINERAL VEINS.

THE local accumulation of minerals in parts of rocks, subsequently to the formation of the rocks themselves, is a very important subject, which requires a special treatise for its proper discussion. All that can be done here is to point attention to a few of the principal facts connected with the structure and mode of occurrence of metallic beds and veins, and to add, in the section on Geological Agencies, some remarks as to the causes by which this distribution of metallic substances has been regulated.

a. Metallic Ores in Beds.

The ores of metals are sometimes found in beds. This is especially the case with the most abundant of all metals, iron. The great majority of rocks contain iron in some form, and some are so highly impregnated with it as to make it worth while to smelt them. The so-called iron-sands of the south-east of England were at one time an important source of iron. The principal sources now used in Great Britain are beds of clay-iron ore, or beds containing nodular concretions of clay-iron ore, found in the Carboniferous and other formations. In Scotland there occur beds of clay-ironstone, containing a large proportion of coaly matter, and requiring, in consequence, little or no coal in the process of calcination. They are known as black-band ironstone.

Hæmatite also occurs in great bed-like masses in some places, as in Furness, where such masses, twenty or thirty feet thick, appear as if interstratified with, but really filling up, hollows in the Carboniferous limestone.*

Some beds of rock also contain copper ore, mingled with the other materials of the rock. The "kupfer schiefer," or copper slate of Germany, is of this character. Many beds of sandstone in the upper part of the Old Red Sandstone of the south of Ireland, contain copper ore disseminated among them. The Lower Carboniferous Sandstone of

* See *Mems. Geol. Survey*—Iron Ores of Great Britain, part i. Introduction by W. W. Smyth, p. 20.

Renfrewshire is in places full of diffused green carbonate of copper, and has been worked as an ore of that metal.

Such accumulations of the ores of metals as have been deposited in the same way as the other materials of the bed or beds in which they lie, either as chemical precipitates or mechanical sediments, do not properly belong to the subject to be treated of in this chapter. When, indeed, the metallic ore no longer remains in the exact form or place in which it was first deposited, but has segregated itself from a state of general dispersion through the mass of a rock, so as to form nodules or concretions in particular parts of it, like the balls of clay-ironstone in many clays, or the balls of fibrous radiating iron pyrites in chalk and slate, or the cubical and other crystals of iron pyrites in many rocks, there is then an obvious connection between such a phenomenon and those to be found in metallic veins. This segregatory and concretionary action, however, is not confined to metallic ores, but is general for all mineral matter, as is shown by the segregation of flints in chalk, chert in limestone, calcareous concretions in clays and sandstones, the formation of hard balls in shales, and that of botryoidal and other globular masses in dolomite.*

We are led, moreover, by almost insensible steps, from the study of such molecular movement in the particles of rocks after deposition, through other occurrences, up to the phenomena observable in mineral veins. It often happens that in breaking open balls of clay-iron ore, crystals of galena (sulphide of lead) and of blende (sulphide of zinc), are found in the cavities of the ball. Nodular lumps of specular iron ore, highly crystalline, and the size of the fist, are found sometimes in the Old Red Sandstone of the South of Ireland, and similar balls of galena in the Carboniferous limestone. These are not rolled pebbles, but small deposits of the minerals, which have been formed in little closed cavities in the rock.

β. Non-Metalliferous Veins, or Veins of Segregation.

Minerals not only occur in a more or less crystalline state in the hollows of closed cavities, or as crystals disseminated through the mass of the rock, but also in veins and strings traversing that mass. These veins are of very various dimensions, from a scarcely perceptible thread up to a width of several feet, and are equally indefinite in length. They are rarely straight for more than a few yards, but are commonly bent at various acute angles, sometimes intersecting each other, and branch and split up in various directions, often ending in tortuous filaments. In some cases a small group of beds, or even a single bed, will show numerous veins, while the beds above and below will be free from them.

* See Chapter XV.

The mineral composition of these veins depends greatly on that of the rocks in which they occur. In limestones the veins are almost always calcite, though perfect crystals of dark quartz occasionally occur ; in siliceous rocks they are almost invariably quartz. Some kinds of rock, however, have veins of particular minerals that usually accompany them. Some red clays that contain beds of rock-salt and gypsum are also frequently traversed by veins of those minerals in the neighbourhood of the beds ; and in the case of gypsum, even in places where no actual beds of that substance occur. The condition of the minerals in the veins is often different from that in the beds. In the case of quartz or calcite, whether the mineral substance in the veins be crystalline or compact, it has a very different structure and appearance from that which it shows in the beds or rock-mass. If compact, it is generally much purer and whiter in the veins than in the beds ; if crystalline, the crystals are much more perfect in form than those which occur in the mass of the rock.

The mode of occurrence of these veins is such as rarely to suggest the idea that they ever existed as open cavities, which were afterwards filled up by the introduction of the mineral substance. The mineral appears somehow to have been segregated from the mass of the rock into the places and forms in which we now find it. It is stated that where quartz veins are found in granite, the immediately-adjacent rock is poorer than usual in quartz.*

γ. Metalliferous Veins.

The metalliferous veins commonly show an essential difference in their form and their mode of occurrence from such deposits of metallic ores as are found in beds and concretions, and such veins of spar as have been just alluded to, as veins of segregation. They may be described as fissures or other hollow spaces in rocks, which have been filled more or less completely by a deposition of spars and ores, or native metals, often mingled with other earthy matters.

By **Spars** we mean crystalline masses of the earthy minerals, such as silica (or quartz), calcite (or carbonate of lime), fluor (or fluoride of calcium), barytes (or sulphate of baryta), etc.

By **Ores** we mean the various unions of the metals with other substances, simple or compound, forming oxides or sulphides, carbonates, sulphates, etc., the metal having to be extracted from the ore by metallurgical processes.

Pure or Native Metals are not often met with, except in the case of gold and platinum, and in some places silver and copper, although the metals antimony, arsenic, bismuth, iron, lead, palladium, tellurium, etc., also occur native sometimes.

* *Trans. Roy. Geol. Soc. Cornwall*, iii. 209.

The mode of production of the fissures and cavities, and that of the deposition of the spars and ores now found in them, has been the subject of much speculation. The facts will perhaps be best understood if we place before the student, in as condensed a form as possible, a description of the metalliferous mineral veins found in the mining districts of the North and the West of England, taking as chief authorities Mr. Westgarth Forster and Mr. W. Wallace * for the one, and the *Transactions of the Royal Geological Society of Cornwall*, especially the papers of Mr. Carne and Mr. W. J. Henwood, for the other.

Metalliferous Veins of the North of England.—The mineral veins described by Mr. Forster are those in the hilly country about the junction of the counties of Northumberland, Durham, and Cumberland, but his descriptions are equally applicable to the mineral veins which occur in the southern extension of this high land (or Pennine chain, as it is sometimes called) that runs through the western parts of Yorkshire into Derbyshire. The rocks in which these mineral veins occur consist of a great series of interstratified shales and sandstones, in the upper parts of which the shales predominate, and have beds of coal interstratified with them; in the middle parts the sandstones predominate, while the coals become thin, and eventually disappear, and groups of beds of limestone begin to come in, at first interstratified with thin coals; but these soon disappear, and limestones, varying in thickness from 3 feet to 130 feet, prevail to a certain depth, but with other shales and sandstones underneath them. Towards the south the limestones increase and coalesce, and the shales and sandstones die out, till in Derbyshire the mineral veins are found in rocks which consist almost entirely of limestone for a thickness of 1000 feet or more. Igneous rocks (basalts and greenstones) occur in both districts, chiefly interstratified with the other beds, and more or less of contemporaneous origin with them. The "Great Whin-Sill" of the north, and the "Toadstone" of Derbyshire, are the chief examples of these igneous rocks.

The total thickness of the mass of interstratified beds in Mr. Westgarth Forster's section is about 4000 feet, and he divides them into two groups, describing the upper 1400 feet as Coal-measures, and the remaining lower part as Lead-measures, the ore found in the mineral veins chiefly containing that metal. He divides those veins into three kinds, which he calls *Rake* veins, *Pipe* veins, and *Flat* or dilated veins.

a. **Rake Veins.**—The Rake veins are described by this author as identically the same kind of fissures as the *dykes, slips*, or *faults* of the Coal-measures, usually accompanied by a perceptible throw or displacement of the beds in the opposite "cheeks" of the vein. He speaks of the veins being *strong*, according to the amount of their "throw," which in some instances reaches to 100 fathoms, or 600 feet; but those which have the least throw are generally the richest in ore, because the richest parts of the mine are those where both cheeks are of hard rock, especially limestone, and a great displacement brings different rocks in face of each other. These veins extend almost indefinitely in length and depth, many of them running in nearly straight lines for many miles, and having no ascertainable termination below. They are sometimes perpendicular, and usually approach that position, their inclination being called the *hade* of the vein, and its amount being reckoned from the perpendicular, and not from the horizontal plane, as

* Mr. Forster's book is entitled a *Treatise on a Section of the Strata, from Newcastle-on-Tyne to Cross Fell.* Mr. Wallace's is called *The Laws which regulate the deposition of Lead Ore.* Stanford, 1861.

coalminers and geologists reckon their *dip*. A slight *hade*, therefore, answers to a high *dip* or inclination, the one being the complement of the other, a dip of 70° being a *hade* of 20°, and so on.

The face of rock on both sides of the vein is called the *cheek* or *side* of the vein, and in inclined veins they are spoken of as the *hanging* and *ledger*, or the *up* and *down* cheeks. The longitudinal direction is called the *bearing* of the vein.

There are said to be some *rake* veins that are wide above and gradually terminate below, being unaccompanied by any *throw* of the beds. These are called *gash* veins. Mr. Forster quotes, as an instance of a *gash* vein, the vein at Llangynnoy, in Montgomeryshire, which, "in the Duke of Powis's time," carried a solid rib of clean lead ore, five yards wide, for a considerable depth, the ore being so clean that it did not require to be dressed, but was simply "poured out of the kebbles at the shaft-head, and carried to the smelting-house." There was an additional thickness of several feet on each side of this gigantic rib of ore, in which the ore was mixed with spar. "This rich and noble vein was at once cut out below by a bed of black schistus, shiver, or plate, and that so entirely that there was not the least fissure or vestige of the vein remaining, nor could any ever be found afterwards, though diligent search was made by the most skilful miners for several years and at several times." He says, however, that he only knows of one instance in his own district of a vein not accompanied by a perceptible *throw* of the beds on the side of it.* These *gash* veins are obviously a difficulty in the way of the hypothesis, which supposes the spars and ores in mineral veins to have been always derived from below.

Dimensions of Veins.—The ordinary rake veins are spoken of as having an average width of three or four feet between their cheeks, that width, however, being subject to great variation, extending even from many fathoms to a single inch; and the veins are often subject to *twitches* or closings, more or less complete, so as sometimes to leave a scarcely perceptible plane of division between the cheeks. The extent of these twitches is quite indefinite both longitudinally and vertically, and they alternate with *bellies* or expansions of the vein of equally indefinite dimensions in both directions. Some veins show great regularity in their width for great distances in both directions, while in others the bellies and twitches alternate rapidly, and the veins are spoken of as *waving* veins.

The veins, moreover, are said to be narrower in the "hazles" or siliceous earths than they are in the limestones, being sometimes "so squeezed" in the siliceous earths as not to be above six inches wide, while in the limestones immediately above or below they are two or three feet in width.† This seems to be obviously the result of the dissolving power of water containing carbonic acid having acted on the limestone walls, and not on the siliceous ones. The inclination of the veins also is apt to vary according to the nature of the rocks they pass through, the approach to the perpendicular being always greater in the sandstones and limestones than in the intermediate plates or shales.

Directions of the Veins.—The veins are divided into two groups, those which run most nearly magnetic E. and W. (or E.N.E. and W.S.W.), and those which cross them at right angles, or run nearly in the present magnetic meridian. The first class are called the *right running veins*, and the second the *cross veins*. The *right running* veins, however, are said by Mr. Wallace to run along bearings which vary from 30° to the N. to 30° to the S. of E. magnetic. The cross veins are more steadily N. and S. magnetic. The right running veins, however, appear to be most steady in character and contents for the greatest distances, some of them carrying good ore, in workable quantity, for eight or ten miles.

Mr. Wallace mentions the occurrence of a third class of small veins running

* *Op. cit.* p. 282, 2d edition.

† Forster, p. 211.

nearly N.E. or N.W., or, according to him, S. 55° E. or S. 55° W. magnetic. These would answer to the *Counter Lodes* of Cornwall.

It appears, however, that there are many intermediate veins belonging to both classes which sometimes unite at acute angles, either coalescing with or crossing each other, and that straight *strings*, or other short irregular branches called *skews*, *backs*, or *sweeps*, occasionally proceed out of each at all angles, and are sometimes as rich in ore as the vein itself.

The map of the mines at Alston Moor, in Mr. W. Wallace's interesting and beautifully illustrated work, is an excellent one by which to study the various directions of the veins in this district. According to the Geological Survey map of Derbyshire, the veins which were laid down by Mr. Warington Smyth, working in conjunction with Professor John Phillips, show both *right running* and *cross veins*. In the northern part of that district there are, according to the maps, several veins running due E. and W. (true) for eight or ten miles, occasionally crossed by others more or less oblique to them, but without any regular cross veins. A group of shorter parallel veins, running about N.E. and S.W., occurs in the centre of the "King's Field," south of Paddington; while in the Winster and Worksworth district there are two or three long right running veins about two miles apart, with intermediate groups of shorter, closely adjacent, parallel cross veins, the bearings of some groups being N.W., that of others N. by W., while others have intermediate points of bearing.

Contents of the Veins.—The veins contain spars and ores, which are sometimes arranged in parallel bands, the ore being either in one rib or several. Some of these ribs are of great dimensions, Mr. Forster mentioning Rampgill vein as having sometimes a width of twelve feet of solid lead ore in the Great Limestone.

Fig. 117.

a. Coating of one mineral, say quartz.
b. Coating of a second mineral, say fluor-spar.
c. Coating of first mineral, or of a third, say sulphate of baryta.
d. Rib of ore, as copper or lead.
w. w. Walls of the lode.

Sometimes these materials are arranged in the way suggested in Fig. 117, giving the idea of successive coatings of the different minerals having been formed at different times on the sides of the vein. Sometimes, however, the spars and ores

are mixed together with great irregularity. Seams of clay also occur, sometimes running parallel to the ribs of ore and spar. These I believe to be the *saalbands* of the Germans; and sometimes clay or decomposed mineral matter (whether rock, or spar, or ore) occupies a large part of the vein, which is then called a *soft* vein.

There also occur masses which are called *riders*. These are said by Forster to be "stony concretions suspended in the vein, consisting of spar, fragments of the adjacent rock, and sometimes bunches of ore, all connected together." These riders are said to vary from five or six inches to as many feet in width, so as to divide the vein into two; and in some instances at least a rider seems to be nothing but an unbroken detached mass of the adjacent rock, fallen into the cavity of the vein. Ribs of ore are sometimes found on both sides of these riders, but usually only on one; and it is said that occasionally one side of a vein is *coated with hard rider*.

The veins are spoken of as *hard* veins and *soft*, apparently according to the state of preservation or decomposition of their stony contents, or whether they are more or less occupied with clay. In the hard veins there are said to occur caverns or cavities, sometimes big enough for three men to turn in. These are called *shakes*, *lochs*, or *loch-holes;* and Mr. Forster gives the following graphic but quaint description of some of these:—"There is generally a hard stony crust, called *druse** or *rider*, at Alston Moor and Allanheads, adhering to the inside of the cavity, out of which, as out of a root, an innumerable multitude of short prismatic crystals are shot, which sparkle like a thousand diamonds with the candle." "Between these clusters of mock-diamonds, and sticking to them promiscuously, there are often lead ore, black-jack,† pyrites, or sulphur and spar, shot also into prismatic, cubic, or other figures; and besides these clusters of grotesque figures which grow out of one another, and are, as it were, piled on one another, the whole inside of the cavern is sometimes most magnificently adorned with the most wildly-grotesque figures, which grow upon and branch out of one another, in a manner not to be described, and with all the gay and splendid colours of polished gold, of the rainbow, and of the peacock's tail." When we come to speculate on the origin of mineral veins, all these circumstances are as necessarily to be taken into account as the occurrence of the metallic ores themselves.

It has been already said that the contents of the veins vary with the nature of the rocks they traverse. The quantity of ore seems always to be least when the veins pass through beds of shale, and greatest in beds of limestone. Mr. Forster expressly says that the veins, in passing through the Great Limestone, which is never more than 130 feet thick, have produced as much lead ore as in all the other beds put together, in a total thickness of about 2000 feet. Mr. Wallace‡ states that the cross veins, and his third class of veins, seldom contain much ore above the Great Limestone, but have much lead ore in the Great Limestone, and lead ore and copper ore in the beds below the Great Limestone. In passing through the beds of plate or shale, the veins rarely contain anything but a clayey substance, called "douk" or "dawk."

Intersection of Veins.—If two neighbouring veins meet each other obliquely, and intersect, they commonly produce a body of ore at their junction, and if both are rich veins the quantity of ore will be considerable, but if one be poor and the other rich, both seem to be either enriched or impoverished by the meeting. If a vein splits into strings, either vertically or longitudinally, it is a sign of impoverishment; if, however, strings come into it, of enrichment.§ It is obvious that this is merely saying the same thing in different words, and it appears that the expected consequences do not always follow.

* Derived from the German *druse*, decayed ore.

† Blende or sulphide of zinc.

‡ At p. 55 of his work.

§ Forster, *Op. cit.*

As regards the intersections of the *right running* veins and the *cross courses*, it would appear that the *cross courses* always intersect the right running veins, and generally *heave* or displace them to the right or left of their course, in the same way that faults would do. If the *contents* of the right running vein are distinctly broken through by the cross course, it is certainly strong evidence that the cross course is newer than the right running vein. If the contents of the cross course be continuous across the interrupted contents of the right running vein, the evidence becomes still stronger. But it does not appear that this is always the case. It has been well observed by Sir H. T. de la Beche that the apparent shifting of mere fissures may possibly lead to mistakes in this matter, and that the vein which has been apparently shifted by the other may really be either contemporaneous with it or subsequent to it, and not necessarily of previous origin, according to Werner's rule. Fig. 118, for instance, shows the intersection of two fissures, one of which, *a a'*, is apparently shifted or heaved by the other marked *b b'*. It is clear, however, that they may both have been formed contemporaneously, and coincided for a certain space, or that even if *a' a* be the newer, it may have run along *b' b* for a space. This would be true, whether Fig. 118 be supposed to be a plan or a section. If a plan, the dislocation would be called a *heave*, if a section, it would be called a *slip*, however and whenever it was caused.

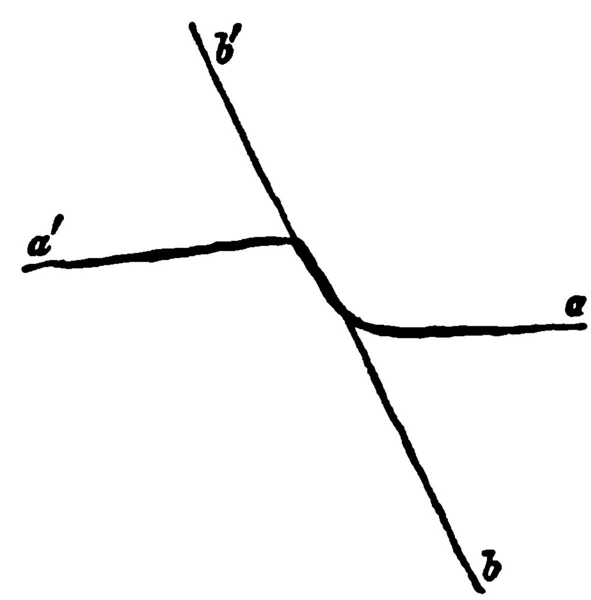

Fig. 118.

It is obvious, then, that it is to the condition of the contents of the veins we must look, rather than to the mere relative position of the veins themselves, for evidence as to their relative date. Mr. Wallace* adduces several facts, such as the abrupt termination of the right running veins at points where they are met by the cross veins, in favour of the opinion that the cross veins are either contemporaneous with, or anterior to, the right running veins, in opposition to the prevailing opinion as to their relative ages.

b. **Pipe Veins.**—A pipe vein in the North of England is described by Westgarth Forster as in many respects resembling "a huge irregular cavern, pushing forward into the body of the earth in a slanting direction," sometimes running between the beds, when those beds are highly inclined, but in other places "bursting their way up through the strata." One that I examined some years ago, with the late Mr. F. J. Foot, of the Geological Survey of Ireland, gave a good idea of these pipe veins. It was a little W. of Tulla, in the County Clare, and showed an irregular, nearly vertically descending chamber in the horizontal limestones, accessible by a winding path on its rocky sides, and in some places expanding to a width of fifty or sixty feet. These sides were lined with a great deposit of crystals of calc-spar, which seems at one time to have filled up most of the cavity, and, I presume, contained masses of crystals of galena in sufficient quantity to render it profitable to extract the great mass of material which must have been removed. Other similar pipe veins, and some true veins, occur in the neighbourhood, and such *pockets* of spar and ore are not of unfrequent occurrence in many parts of the great limestone of the British Islands, which is known as the Carboniferous Limestone.

It may always be difficult to prove that *pipe veins* are not connected with some fissure which may, or may not, be a *rake vein;* but, so far as the evidence goes, they seem to have been mere cavernous spaces excavated out of the rocks, in the same

* *Op. cit.* p. 80.

way as all other caverns, and afterwards to have become the receptacles of spars and ores.

Mr. Forster also speaks of a variety of the pipe veins, which he calls the "accumulated" vein. But this seems to be rather a highly inclined pipe-like cavity, formed by the intersection of two or more "rake" veins. He says they approach the form of vast irregular cones, some of which have the apex upwards, and some downwards. "When the ore is worked out of a large accumulated vein it exhibits a horrid and frightful gulf, some of which may be fifty or sixty feet wide below, and they are often worked down to a great depth from the surface." "The excavation of the perpendicular irregular pipe is of itself sufficiently frightful; but when the hanging rocky sides of the main pipe or cone are slitted up and opened, perhaps, from top to bottom in many places, in working collateral diverging veins, the appearance of this horrible gulf is then awful beyond description." "Many iron-mines are found in this description of vein, and lead and copper ore are frequently found and worked in both the sorts of 'accumulated veins.'"

c. **Flat Veins.**—The flat veins are in reality pipe veins, which, instead of a more or less tubular cavity, take the place of a certain bed or beds, parts of which have been removed by the erosion of water. They are consequently flat cavernous spaces of greater or less dimensions, the roof of the cavity being supported by the parts of the bed which have been left uneroded. The open spaces thus left have been subsequently filled more or less completely by the deposition of spars and ores, sometimes in alternate layers, sometimes in irregular masses, in the same way as happens with the contents of the rake veins. The uneroded parts of the original bed or beds are spoken of by Forster as *twitches* of the flats in the same way as in the *rake veins.* He says that these flat veins seldom carry ore very far from the neighbourhood of the *rake veins*, with which they always appear to be connected.

A curious circumstance is mentioned by Mr. Wallace, that, not only are the joints in the limestone near the surface wider than they are below, and filled with seams of clay (both circumstances being obviously due to the action of the weather), but that the flats are in those places traversed by the same joints, and also filled with clay.* It has been before pointed out that at great depths joints, although they exist as mere planes of division, are often quite imperceptible in rocks, which sometimes will not even separate along them till the weather has had time to act upon them. But joints may be of very different ages, and it may easily have happened that some have been formed since the formation of the *flats*, and equally widened by the percolation of water which has afterwards introduced the clay, as in the limestone above and below.

Metalliferous Mineral Veins of the West of England.—In the west of England the *rake veins* are called *lodes;* the *pipe veins*, perhaps, scarcely occur at all, unless those called *carbonas* represent them, and the *flats* seem to be analogous to the *floors* in their mode of occurrence, though hardly so in their origin. These *floors* seem chiefly or solely to contain tin ore. The *cheeks* of the veins are called *walls*, and when they are inclined they are spoken of as the *hanging* wall and the *foot* wall, or those which, when he is in the lode, hang over the head, or lie under the foot, of the miner. The inclination of the vein is called its *underlie*, and, like the *hade* of the north, its angle is calculated from the vertical and not the horizontal plane,† though Mr. W. J. Henwood ‡ proposes to use it in the same sense as the *dip* of the coal-miner.

The rock traversed by the lodes is there called the "country." Mr. W. J.

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* *Op. cit.* p. 54.

† I am indebted to Mr. Curwen Salmon for calling my attention to this fact, which had previously escaped me.

‡ *Trans. Geol. Soc. Corn.*, v.

Henwood * speaks of some lodes as if they were mere bands of rock impregnated with ore, without having any distinct walls, and without showing any fissure; but these, I think, must be exceptional cases. It seems that the "country" on each side of the lode is sometimes so impregnated with strings and bunches of ore, that if the actual fissure be narrow its very occurrence may be masked by them. Still it also appears that tin ore occurs disseminated through parts of the granite, as if it were a constituent of the rock. I have myself got specimens of granite on Shap mountain in Cumberland, with iron and copper pyrites diffused through it in crystals, in the same way that the crystals of felspar are, and gold is said in like manner to occur in many parts of the world in granitic and other rocks, in diffused grains, as if it were a constituent of the rock. Mr. Henwood frequently points to these facts.

Lodes.—The lodes of the west, like the *rake* veins of the north, seem to have been originally faults. The fact of a dislocation having taken place may be much less obvious in the rocks of the west than in those of the north of England, but Mr. Hawkins † expressly says that dislocation always accompanies the lodes, and that the result is that the walls no longer fit into each other, but convexity comes opposite convexity, and concavity opposite concavity. He also shows that along some veins dislocation has taken place more than once, and that fresh concavities have been thus produced, subsequently filled by fresh deposition of spars and ores. In Sir H. T. de la Beche's Report this subject is well illustrated, and the fact of movements of displacement having occurred at different times along the same vein is rendered very probable.‡ According to Mr. Henwood also, it would be impossible to draw a straight line in the vein for any great distance, so as to connect the different *levels* or working galleries in the vein, and the sides of the lodes are less smooth and even than those of the elvans. There seem also to occur in the west lodes resembling the *gash* veins of the north, as the North Vervis lode, at Balnoon mine, in the parish of Lelant, which, after expanding and contracting from a width of a few inches to 20 or 30 feet in the various levels, is, at a depth of 80 fathoms (480 feet), "completely surrounded on the ends, sides, and bottom, by the hard granite, without leaving the slightest trace of its farther existence in any direction.§

Dimensions of Lodes.—The lodes of the west of England seem to be more regular in width than those of the north, though different lodes vary in width from a mere line to as much as 40 feet. It appears that an average of between 3 and 4 feet may be taken for their width, that average being rather greater for the veins traversing slate than those running through granite. Lodes often change their dimensions in passing from one rock to another, but not according to any fixed rule, sometimes becoming wider, sometimes narrower, in passing from slate to granite, and sometimes showing no change. ‖ The length of the lodes is sometimes as much as seven miles, which Mr. Carne gives as the length of the United Mines lode, the longest which he knew of. Mr. Henwood, however, expressly says ¶ that it is not at all certain that the same lode was ever worked for more than a mile in length. He attributes this uncertainty to the fact that "they throw off into the containing rock *shoots*, *strings*, and *branches*, in such abundance, that instead of one *champion lode* the whole forms a complex network of veins; the lode first discovered dwindles, while some of its offshoots swell out, and rival or surpass it in size." ** These are evidently analogous to the *strings*, *skews*, *backs*, and *sweeps* of the north, and may accompany a more or less regular fracture, either outside or within its walls. It is advisable, in these statements, carefully to separate the formation of the fissures and cavities, the deposition of minerals in those cavities,

* *Op. cit.* v. p. 235. † *Op. cit.* ii. p. 225.

‡ *Report on the Geology of Devon and Cornwall*, p. 344.

§ J. W. Henwood, *Op. cit.* v. p. 26. ‖ Henwood, *Op. cit.* v. 234.

¶ *Ib.* p. 175. ** *Ib.* 177.

and the formation of crystals of spars or ores in the "country" or rock immediately adjacent to the cavities. It may be added that the *cross courses* are shorter and more variable in width than the right running veins.*

Directions of the Lodes.—The lodes of the west are also, like those of the north, classed as *right running* lodes and *cross courses*, called at St. Just *guides*, and St. Ives *trawers*, in addition to which there is an intermediate class spoken of as *counter* or *contra* lodes. Mr. Carne† defines the *right running* lodes as those which do not vary in direction more than 30° from E. and W., the *cross courses* as those which run within 30° of N. and S., and the *contra* or *counter* lodes as those which have any of the intermediate bearings. He speaks of *flukans* as veins containing only whitish or greenish clay, and of those which run parallel to the *cross courses* as *cross flukans*. The term *flukan*, however, probably indicates merely the clay, which is the principal contents of some veins. *Slides* are said to be greatly inclined veins,‡ which generally run E. and W., and rarely N. and S. The term *heave* is used to denote the shifting produced by the intersection of one vein with another when regarded *in plan*; the term *throw*, when regarded in a vertical section.

The downward direction of the lodes is quite indefinite, as neighbouring veins sometimes underlie in the same direction, either at the same or different angles, sometimes towards each other, at a similarly various inclination. Mr. Henwood gives an angle of 70° from the horizontal as about the mean inclination of the lodes in Cornwall.

Contents of the Lodes.—The *spars* or *veinstones* found in the lodes of the west are chiefly siliceous, either mere silica, as quartz, jasper, or chalcedony, or silicates.§ Schorl, or tourmaline, or "cockle," occurs rather frequently, especially in tin-mines, and then generally above that ore, so as to give rise to the miner's saying that "cockle rides on the tin." Fluor-spar, sulphate of baryta, and other minerals, also occur, and sometimes, but more rarely, calcite or carbonate of lime. The principal ores worked are those of tin and copper; but ores of lead, iron, zinc, cobalt, and silver, and native bismuth and native silver, also occur.

The earthy contents of the lodes are clays of various kinds, generally spoken of as *flukan*, and such substances as *peach*, which is a green chloritic clay, and *prian*, a soft white clay. The *gossan*, which is often mentioned, appears to be a rusty-brown ochrey substance, deriving its colour from the weathering of some ferruginous compound, and chiefly confined to the upper parts of the lodes. The clays are probably the "saalbands" of the German miners, and they sometimes occur in more or less regular seams or bands, parallel to the bands of ore or spar, but sometimes apparently dispersed irregularly through the other contents of the lodes.

There is, moreover, the substance called *Capel*, which forms siliceous bands on the sides of the lodes, often containing hornblende or tourmaline, and often coloured with chlorite or other green substances, and either being a more silicified condition of the "country" at the sides of the lodes, or a deposit on the walls of the lodes. I was indebted to Mr. Curwen Salmon for calling my attention to these singular "capels," which appear always to accompany the more productive parts of the lodes. His belief is that the actual fissures of the lodes are rarely wider than the thickness of a finger, and that the ores and spars are not so much formed in the fissure as in the "country," or rock at each side of it, and that where the fissure passes through *uncongenial* rock none of these minerals occur

* Carne, *Trans. R. Geol. Soc. Cornwall*, vol. ii. † Carne, *Ib.*

‡ ? From the perpendicular.

§ Mr. Henwood says (*Op. cit.* vol. v. p. 179), that where the contents of the lodes are most uniform they consist chiefly of quartz, and are there regularly jointed; and, when speaking of the general composition of the lodes, at p. 204, he says, that much the largest proportion of the mineral contents of the lodes consists of quartz.

in its sides, but that where the rocks were *congenial*, the walls became highly charged with silica, but not as free quartz, as it is in the lode. These silicified walls are called the "capels," and they are often accompanied by ore.

In addition to the "capels," some of the lodes contain "riders," which, however, in the west of England appear always to be detached masses of the adjacent "country," fallen into the cavity of the lode, or enclosed between two branches of the lode. That part of the contents of the lode which occurs next the present surface, so as to have the spars and ores affected by the weather, is called "the back" of the lode. The copper ores are often found in the state of malachite or carbonate of copper in the backs of the lodes, while below they pass into sulphides. The contents of the lodes, and sometimes, I believe, the walls of the lodes themselves, frequently exhibit those polished striated surfaces which are known as "*slickensides*."

Mr. Henwood has some interesting observations on the relations between the kinds of ore occurring in the lodes, and the variations in the kind of country they traverse.* He says that some lodes have copper ore only in the slate, and tin ore only in the granite; that the Wheal Breague lode, in passing from the granite to the slate, instantly loses its tin ore, while Wheal Vor has tin ore in the slate, but is worthless in the granite. In the St. Austell district copper ores abound in the softer schistose rocks, but in quartzose slate, mica-schist, and granite, tin ores only are found. The Tresavaen lode, however, gave enormous quantities of copper pyrites in the granite, but was exceedingly deteriorated on entering the slate. At Botallack a lode passes three times from granite to slate, containing none but tin ore in the granite, and none but vitreous copper ore in the slate. Notwithstanding the occurrence of enormously rich bunches of tin ore in slate at Wheal Vor and other places, and valuable discoveries of copper pyrites at Tresavaen and elsewhere, yet the lodes in granite, elvan, and hard massive slates have yielded beyond comparison the largest quantities of tin ore, and of vitreous and earthy black copper ore, and rare crystallised varieties and uncommon compounds of copper; while the lodes in the softer slates have chiefly afforded massive copper pyrites, and seldom any other varieties. Lead ore only occurs in lodes which traverse blue or greyish slates, generally at a great distance from the granite.† This, however, is directly the reverse of what takes place in Wicklow, where the lead ores occur in veins which traverse both granite and slate, while the sulphur and copper ores generally occur in slate and trap rocks at a distance from the granite.

Much the largest proportion of the mineral contents of the Cornish lodes consists of quartz, mingled with gossan in the upper parts, but in some lodes in granite gossan is found at great depths. *The greatest number of rare and curious minerals are found in these gossany parts of the lodes*, evidently the result of comparatively recent actions and reactions under atmospheric influences. Iron and copper pyrites are by far the most abundant ores in the lodes, and they are mixed in every possible proportion.‡ Almost the whole mineral wealth of Cornwall appears to occur within two or three miles of the line of junction of the slate and granite, yet no part of that tract is said to be richer than another, nor are the lodes which have one wall granite and the other slate generally the richest lodes.

There are also in Mr. Henwood's paper § many interesting observations on the mode of occurrence of the ores and the substances associated with them. When tin ore is found in a lode traversing slate it is always accompanied by *capel*, *i.e.* the slate is hard and quartzose, and the tin ore is more minutely dispersed, *i.e.* in smaller granules, than it is in the lodes which traverse granite, where the crystalline granules of tin ore rarely exceed a pea in size. In slates near

* *Op. cit.* vol. v. p. 190.
† *Ib.* 224.
‡ Henwood, *loc. cit.*
§ *Ib.* p. 226, *et seq.*

fossiliferous localities (East Crennis, Fowey Consols, etc.), the large lodes contain chiefly white crystalline cavities, with drusy cavities called "*vughs*," which appear to answer to the cavities in the veins mentioned by Mr. Forster (see p. 296). These vughs are said to be fewer in the neighbourhood of the granite, but when they do occur to be of larger dimensions. It is also stated that many of the largest and richest bunches of tin and copper ore are found close by cross-courses and flukans, and often only on one side of them, the lode on the other side of them being worthless.* As these cross-courses and flukans commonly contain substances which interrupt the flow of water in the lodes, it would seem as if there were a connection between that flow and the deposition of the ore.

Intersections of the Lodes.—Mr. Carne, depending on the facts relating to the intersection of the different lodes, divides them into different classes, according to age, as follows:†—1st, *The oldest tin lodes* which generally underlie to the north, and are traversed and heaved by 2d, *The newer tin lodes*, generally underlying to the south. These are almost always *right running* lodes, but at St. Just some *counter lodes*, and at Polgooth one cross-course, contain tin ore; 3d, *The oldest right running copper lodes* mostly underlying to the N., but some to the S., while some change their underlie. These are the principal lodes. The most promising are those which have *gossan* or rusty iron ore on the *back*. The junction of two of these copper lodes, with no apparent intersection, is said to be common, and it is also said that when they underlie in the same direction, but meet in consequence of the difference in their angles, the richness of the mine is increased, but if their underlie is in different directions they become barren where they meet. A sudden change in the richness of the lode is said to be the result of a change in the slate rather than the nature of its contents, as from a hard quartz or cassel to a "soft chlorite called peach." Most of these lodes have small interrupted "flukan veins." Some have tin above and copper below, only one being known to have had copper ore above tin. The nature of the rock traversed seems to have an effect on the richness of the lodes. No very rich copper-mine occurs wholly in granite, but in some there is an improvement in passing from the slate into the granite, while in others the reverse was observable, and in some no change was perceptible. The richest part of the mine is said to be generally about the junction of the two rocks, especially when one wall is granite and the other slate. 4th, *Contra copper lodes*. These generally contain more flukan than the last class, but are often as productive in copper. 5th, *The Cross-Courses*. Their width is often greater and more variable than that of the preceding classes. Their underlie is various, sometimes to the E. and sometimes to the W., but those which point to the E. of N. generally underlie to the W., and *vice versa*. They are the cause of great trouble by shifting the right running veins, and sometimes "cutting out all the riches," but are sometimes advantageous in consequence of their flukan keeping out the water. They often contain iron ores, such as hæmatite and specular iron; and lead ore chiefly occurs in them. They do sometimes, however, contain copper and tin. 6th, *More recent copper lodes*. Some E. and W. copper lodes which are said to cut the contra lodes and cross-courses are placed in this class, and also some containing lead ore. These are said to have more flukan than the preceding classes. 7th, *Flukans*, and 8th, *Slides*, contain nothing but clay, but are said to intersect and heave all the rest, and the *slides* to affect the *flukans*.

This arrangement is a graphic way of representing the facts, but it has already been pointed out that the intersection of veins, unless observed with great caution, is a less trustworthy ground of determination of their relative dates than it would be in the case of the intersection of dykes and veins of igneous rock. Dr. Boase, in a subsequent paper, points out that there are exceptions to all Mr. Carne's classes

* Henwood, *Op. cit.* 233.

† In his well-known paper already cited, *Trans. Roy. Geol. Soc. Cornwall*, vol. ii.

of veins. Mr. Carne more recently observed that when lodes intersect or unite at a greater angle than 45°, the union is not productive, but if they meet at an angle of 20° or 30° the richness of the veins is generally increased.*

It appears that the rule as to the directions of the *heaves*, when one vein is cut by another, though in many cases the same as the rule as to the *heave* or *throw* of an inclined bed when intersected by a fault, is by no means invariably so. If, however, an inclined vein existed, and was filled up by spars and ores, and that vein were cut by a fault which afterwards became a mineral vein, there would be no reason why the direction of its *heave* or *throw* should be different from that which it would have had if it had been a bed intersected by a fault. When this rule is not followed, then the evidence as to the relative age of the intersecting lodes becomes untrustworthy.

Carbonas.—The carbonas, which Mr. Henwood says are analogous to the pipe veins of the north, appear to be cavernous spaces which, however they were formed, were subsequently filled with spars and ores, and other matters, in the same way as the pipe veins were filled, namely, by the deposition of those matters from percolating waters. He describes the one which occurs in the St. Ives Consolidated mines† as a large chamber-like enlargement of the lode, from which strings and veins branch off in all directions. It is in the granite, and varies from 24 feet to 60 feet in height and width, and has been traced for 240 yards lengthwise. Its contents are quartz, felspar, schorl, and oxide of tin, irregularly disseminated, but in parts it contains fluor (which the lode does not), chlorite, common and blistered copper pyrites, iron pyrites, and traces of vitreous copper ore or copper glance. "The whole may be described as an assemblage of *pipes*, *strings*, *branches*, *shoots*, and *veins*, converging into one grand trunk, which extends to the S.E., dipping at 1 in 6. It is on all sides surrounded by hard granite, and nowhere reaches the surface."

Floors of Tin Ore.‡—The "floors" are spoken of as beds, and beds of "samet" and "hornblende slate" are mentioned; and also floors of ochraceous ironstone alternating with the tin stone. They are said to dip at the rate of three feet in a fathom (27°) to the north, and to have been worked for a distance of forty fathoms both on the dip and the strike. It would appear as if the rock (granite, elvan, and killas, but chiefly the former) had been impregnated by rather irregular but parallel layers, or short interrupted veins of tin stone. In Trewellard there were perhaps twenty floors of tin stone in the slate, within forty-two feet of the surface, one of them being two feet thick and two feet wide, and they occurred near the junction of several tin *lodes*.§ At Botallack tin floors occurred both in slate and in granite, both near the junction of tin lodes, and where no such junction took place: the "floors" of tin ore alternated with floors of the "country" (whether slate or granite), each being from six to twelve feet thick, and from ten to forty feet across. They were always found on one or both sides of a tin lode, but sometimes only connected with it by a string.‖ Copper ore also sometimes occurs in floors.§

Gold Mines.—Gold is found disseminated in grains, crystals, threads, pockets, "nuggets," and other irregular forms, through many different rocks. It is very commonly associated with the quartz of quartz veins, also in granite, gneiss, schist, etc. But it is also more rarely met with

* *Trans. Geol. Soc. Cornwall*, vol. ii. p. 306. † *Ib.* vol. v. p. 16.

‡ Described in a paper by Mr. Hawkins in the 2d vol. of the *Trans. Roy. Geol. Soc. Cornwall*, "On the stratified deposits of tin stone, called tin floors," which, however, I have not found very easy to understand.

§ Carne, *Op. cit.* vol. ii. Mines of St. Just.

‖ Carne, *loc. cit.* ¶ Henwood, *Op. cit.*

in the form of grains in the shales and other unaltered stratified rocks. It usually occurs as native gold, that is pure, or only slightly alloyed by its mixture with other metals. It is often found mixed with iron pyrites, or with silver, as silver is with galena. The veinstone in which gold is found is generally a pure white quartz, in which other ores are sometimes mixed, especially those of iron, usually in the form of iron pyrites.

In the auriferous districts of Australia the veins of gold-bearing quartz are spoken of as "reefs." The regular parallelism of the north and south quartz veins, laid down on the beautiful maps of the Geological Survey of Victoria, under the direction of my old friend and colleague Mr. R. A. C. Selwyn, suggests the idea of these reefs being regular lodes. An excellent digest of Mr. Selwyn's operations is given in *Notes on the Physical Geography, Geology, and Mineralogy of Victoria*, by himself and his colleague Mr. Ulrich, published in Melbourne in the year 1866. These quartz "reefs" are described at p. 13 and elsewhere, and they are especially well delineated on the sheets of the map, Nos. 9, 13, 14, and 15. They are said to be inclined at all angles, both to the E. and the W., varying from the vertical to the horizontal, occasionally coinciding with the planes of the strata, sometimes with those of the joints, or the cleavage, and occasionally crossing all. They vary in width from a mere thread to 130 feet. These quartz veins have been mined to a depth of 590 feet, stone from that depth having yielded five ounces of gold to the ton. The slates traversed by these quartz veins are of Lower Palæozoic age. One curious fact mentioned is, that in the deeper parts of the quartz reefs the gold is disseminated in more minute particles than nearer the surface; and that no "nugget" has ever been found in a "quartz reef," at all rivalling in size those more magnificent masses found in the alluvial deposits, which are of course derived from the waste of still higher parts of the reefs than those which now appear on the surface.* The gold procured directly from the "quartz reefs" mostly occurs "in hackly grains, thin plates with ragged edges, often above one inch square, in filiform shapes and irregular crystalline masses, but very rarely arborescent or reticulated. Perfect crystals of gold occur generally in the clayey or ferruginous ochry casings of the reefs, near the surface." These crystals occur there under the same conditions as those rarer mineral forms found in Cornwall in the gossan on the "backs" of the lodes, where the minerals have been acted on by the weather. In the deeper parts of the quartz reefs there is often no appearance of any gold at all, although it is diffused through the mass of the veinstone in very profitable quantities. There is a very remarkable speculation of Mr. Selwyn's, to the effect that the large nuggets found in the drift of certain localities, and not in the "reefs" or even in the drift of other districts, may perhaps have been increased in size by the passage of water through the drift, containing gold in solution, and depositing it on the smaller masses already existing there. In support of this speculation it is stated that auriferous iron pyrites occurs in the cavities of pieces of driftwood in these gravels, and in the form of roots and branches of trees. Mr. Selwyn also states that Mr. Daintree has observed that a speck of gold lying in a solution of chloride of gold, was increased several times in size after a small piece of cork had fallen into the solution, as if the presence of organic matter, which is found abundantly in the drifts, contributed to the deposition of gold from its solution. Mr. C. Wilkin-

* The largest "nugget" ever found in a quartz reef is said to have weighed fourteen pounds, and to have been got at a depth of forty feet. The largest nugget found in the gravels is said by Mr. A. Phillips to have weighed 233 lbs. 4 oz. troy.

son, of the Geological Survey of Victoria, likewise observed that not only particles of gold, but those of many other metals and minerals, immersed in a solution of chloride of gold, received coatings of gold when any organic matter, as a chip of wood, was dropped into the solution. Mr. Selwyn remarks that the waters that passed through the drifts during the outpourings of the great basaltic masses which, near Ballarat, etc., overlie some of the auriferous sands and gravels, would probably have been more or less thermal and saline, and it is only in the regions where these basaltic plateaux occur that the large "nuggets" are found in the drifts, those of other districts rarely exceeding an ounce in weight. Here, again, we have a curious coincidence of argument in favour of the aqueous and comparatively modern origin of many of our metalliferous deposits.*

Many other metals besides gold occur in the auriferous "quartz reefs" or lodes of Australia, especially the ores of copper, lead, tin, and iron, but they are comparatively neglected by the miners. Numerous spars also occur, many of them of the kind called "precious stones," or gems.

A work has lately been published by Mr. A. Phillips, entitled *The Mining and Metallurgy of Gold and Silver*, in which the student will find ample information on this subject. It is there stated that Mr. Selwyn, judging from the comparatively poor gravels of an older tertiary period, compared with those of a more recent date, has come to the opinion that there must have been two sets of quartz reefs, one comparatively poor, preceding the Miocene period; while the more recent sets of reefs were of a richer character.† It is, however, obviously possible that the same set of "reefs" may have become, in the latter period, more richly impregnated with gold that they were previously.

Mr. W. J. Henwood has in the press a work on Mining, of which he has been so kind as to let me see the proof sheets of the part relating to the gold-mines of Minas Geraes in Brazil. They are full of the most valuable descriptions and details, but rather adapted to the professed miner than the student. I gather, however, from his descriptions, that there is a great series of rocks, consisting of granite, gneiss, micaceous and talcose schists, and clay-slate, all in places impregnated with gold. In one part, gold in grains is said to occur as one of the constituents of the granite, and to be scattered here and there through the whole series of other rocks. Veins of auriferous quartz, either veins of segregation or lodes, occur, either coinciding with the stratification, the cleavage, or the joints, or crossing them all obliquely. Bands of different kinds of iron ores are said to occur in some of the clay ironstone interstratified with the slates, and associated with these are certain conformable beds, from which the greatest riches of gold have been obtained. These vary from two to six inches in thickness, and extend for many feet or fathoms, containing lumps, flakes, and granules of gold, sometimes isolated, often clustered, but generally united by intertwining threads of gold. These layers are said to get gradually poorer in gold, and merge into the neighbouring strata. They seem, in their mode of occurrence, to resemble the iron pyrites (sulphur ore) of Wicklow, except in their much smaller quantity. Mr. Warrington W. Smyth long ago described ‡ the latter minerals as occurring not in a lode with distinct walls, but as impregnating the slate in great quantity in a certain band of country, running N.E. and S.W. for about nine miles, and perhaps accompanying a lode or fissure.

An analogous mode of occurrence of silver is mentioned by Mr. A. Phillips §

* The student will find much useful information on these gold-reefs, and the theories as to their origin, in Mr. Brough Smyth's handsome volume on the *Gold Fields of Victoria*, Melbourne, 1869.

† Page 107.

‡ In the *Mining Records of the Geological Survey*, vol. i. p. 3.

§ *Op. cit.* p. 253.

in his description of the silver-mines of Norway. He says, "These mines are situated in gneiss and mica-schist. . . The silver occurs in what are called fahlbands, which consist of parallel belts of rock . . the direction of which is nearly N. and S.; they are irregular in their dimensions, but constantly preserve a certain degree of parallelism with each other, and may be traced for an extent of several miles." . . The fahlbands are themselves traversed by true veins containing silver ore, but only when they intersect the fahlbands.

Stanniferous and Auriferous Gravels: Stream works.—Tin and gold, two of the most valuable, and one of them the heaviest of metals (except platinum) have been procured, and are still being procured, in different parts of the world, not only in veins, or from the mass of rocks, but from the clays, sands, and gravels of river valleys in which the debris of the rocks has been deposited. Their occurrence there is obviously no part of our present subject, and it may simply be noted that many of these deposits are richer in ore than any part of the mass of the rock or veins from the degradation of which they have been derived. This manifestly results chiefly from the destruction of these rocks having been effected by the forces of denudation, and the greater specific gravity of the metals having rendered their transport less easy than that of the rock. The siliceous, argillaceous, and calcareous particles have been carried off, the heavier metalliferous ones have been left behind.*

The theoretical considerations suggested by mineral veins do not come within the scope of the present or geognostic section of this Manual. This will be discussed in the section on Geological Agencies.

Explanation of some Mining Terms.†

Adit—The gallery or level driven in from some neighbouring low ground to cut a vein.

After-damp or Choke-damp—Carbonic acid gas, which usually succeeds to an explosion of "fire-damp" in a coal-mine.

Attle—The refuse of the workings of a vein mine.

Back of a lode—The part near the surface, or that above the adit level, generally more or less affected by weather.

Black jack—Zinc blende, sulphide of zinc.

Board, or Brow—The gallery in a coal-mine which is cut across the "face" of the coal.

Brattice—A wall of timber or brick, either dividing a shaft into compartments, or erected across a gallery either temporarily or permanently.

Buddle—A trough for washing pounded ore, and separating it from the gangue.

Capels—Siliceous bands at the sides of the lodes in Cornwall, etc.

* Many curious and interesting accounts of the washing for tin and gold will be found in the works already referred to, and in other similar ones.

† In the last edition of this Manual there was a chapter containing some notes on the art of mining. The publication of Mr. Warrington W. Smyth's little work on *Coal and Coal-mining* renders any remarks of mine on that subject quite superfluous, and I hope he will shortly give us a similar book on "Vein-mining." It may be useful, however, to retain in an amplified and corrected form the explanation of mining terms.

Carbona—Cornish name for a large cavernous enlargement of a lode.
Cauk—Barytes, sulphate of baryta.
Champion Lode—The main vein, as distinguished from lateral strings and branches.
Cockle—Cornish term for either schorl or hornblende.
Coffins—Old works on the tin-lodes in Cornwall.
Costeaning—Sinking shallow pits at intervals down to the solid rock, and then driving headings at right angles to the general course of the veins in a country, for the purpose of discovering ore.
Counter, Contra, or Caunter Lode—A lode cutting a "right lode" obliquely between it and the cross course.
Country or Ground—The mass of rock through which a vein runs.
Cross Course—A lode more or less nearly at right angles to the main or right running lodes of a district.
Cross Cut—A horizontal gallery not driven in the lode.
Cross Flukan—A vein of flukan running like a cross course.
Deads—The rubbish left behind in working a vein-mine.
Dead Vein—A northern term for one that carries no ore.
Douk or Dauk—A northern term for a mass of clay in a vein.
Fahlbands—A Norwegian term for belts containing silver ore, which run in parallel N. and S. lines, but seem to be interstratified with the slate-rocks.
Fire-damp—Carburetted hydrogen gas, which, when mixed with a certain proportion of air, becomes explosive on the application of flame. In some coalfields it is called *sulphur*. Sir H. Davy showed that a mixture of seven volumes of air to one of fire-damp is the most explosive compound; when the proportions of atmospheric air are less than four or more than fourteen to one of fire-damp, it is not explosive.
Flats—A northern term for deposits of ore that take the place of beds.
Floors—See *tin-floors*.
Flucan or *Flukan*—A vein or seam of clay, or any impure argillaceous substance occurring in a vein.
Foot Wall—The under wall of an inclined vein.
Gangue—The matrix of the ore in a vein.
Gate-road.—A gallery driven along the "face" of the coal, a main passage or road in a mine. Gate literally means that through or along which you *go*. In many towns the old streets are called gates, not because they lead to what we should now call the gates of a town, but because they were the places for *going* along. A gate is properly a passage, not that which stops it.
Goaf, or Gob—The more or less empty space left by the extraction of a seam of coal.
Gobbin—The refuse fragments left in working a coal-mine, often piled up to support the roof in the part worked out.
Gossan—A brown ochrey substance, often found at the surface part of a lode; it consists of oxide of iron, often in a powdery state, like ordinary iron rust, coating quartz, or other substances in the vein.
Growan—Granite decomposed *in situ*, often at great depths.
Guides—The name applied to *cross courses* at St. Just, Cornwall.
Hade—The inclination of a vein or fault from the perpendicular.
Hanging Wall—The upper wall of an inclined vein, or that which hangs over the miner's head when in the vein.
Heading—A small gallery driven in advance of a gate-road, or for any temporary purpose.
Holing—Cutting under a bed of coal for a certain distance, so as to deprive it of support, and allow of its falling down when cut away at the sides, or when wedges are driven in at the roof.
Horse—Commonly applied by vein-miners to any large detached mass of rock

occurring in a vein, or lying between two branches of a vein: by colliers to any mass of rock occurring in the coal.

Jackey or Jackhead Pit—A small shaft sunk in a coal-mine for any temporary purpose.

Killas—The Cornish term for clay-slate, especially when fragile and easily breaking into small fragments.

Leader—A string or small vein which leads to the main vein, or is supposed to do so.

Level—A horizontal gallery driven in a metalliferous vein.

Loch, or Loch-hole—A northern term for a cavernous space in a vein, sometimes large enough for three men to turn in.

Peach—Any soft green chloritic-looking substance in a vein.

Pitch—A portion of a vein prepared and set apart for working.

Pit eye—Coal left surrounding the bottom of a shaft, so as to prevent the rocks about it or the shaft itself being shaken.

Prian—A Cornish term for soft white clay in a vein, which is supposed to be a good indication of ore.

Quick Vein—A northern term for a vein that bears ore.

Rake Vein—A northern term for a fissure or fault which carries spar and ore.

Rider—A mass of rock or of compacted fragments in a vein.

Rising—Excavating upwards.

Shaft—A pit open to the surface.

Shakes—The same as lochs.

Shoad-stones—Fragments of ore found in a stream below where it crosses a vein; *shoading* is searching for these stones in order to find the vein. Sometimes the stream may be banked up so as to make a small lake or pond, which is then suddenly let loose in order to wash the bed of the stream bare, and disclose any veins or lodes that may cross it.

Sinking—Excavating downwards.

Skew—A northern term for a fissure or vein striking out irregularly from the main vein for a short distance.

Slickenside—A polished striated surface of a bed, joint, fissure, or vein, or any other rock or mineral surface.

Slides—Cornish name for veins of slimy clay in fissures, generally running E. and W.

Spar—Crystals of any non-metallic mineral.

Stemples—In Derbyshire, the shafts of the vein-mines are often ascended and descended, not by ladders, but by pieces of wood, called *stemples*, fixed in the side of the shaft.

Stope, or Step—The parts of a vein in work; one set of men having proceeded, another set follow them and excavate the next step above or below the first, according as the *stopes* are *overhand* or *underhand*. *Overhand* stopes are those where the miners excavate the stuff above a level by successive steps upwards, building stages as they proceed, in order to catch the stuff as it falls. *Underhand* stopes are those in which they dig down below a level in successive steps, likewise erecting stages as they proceed, and leaving or making a permanent roof or covering to the level below.

Stowces—In the part of Derbyshire known as the King's Field, any man who can discover a vein has by ancient law the right to work it. He makes his claim by fixing up a windlass, or a small wooden model or imitation of a windlass, called a *Stowce*, which, if not removed by the lord of the soil within a certain short time, makes him owner of the mine.

String—In the north a small fissure which runs in a straight course at an oblique angle from a main vein, and either terminates or leads into a parallel vein.

Sweep, or Back—A northern term for a fissure containing ore which sweeps off from the hanging wall of a vein and comes back into it again.

Tamping—A term used in blasting, either in a mine or a quarry, to signify the clay, sand, or rubbish rammed down on the powder in a bore-hole, for the purpose of preventing the powder from being merely blown out of the hole as from a gun, and compelling it to *burst* the rock in which it has been drilled.

Tin-floors—Horizontal layers of tin ore, which seem as if interstratified with the including rock.

Trawn—The name given at St. Ives to a *cross course*.

Tributers—A Cornish term for men who undertake to get a certain "pitch" of a vein for a percentage of the profits, varying perhaps from a quarter to three quarters, according to the richness or poorness of the vein.

Tubbing—In sinking a shaft for a coal-mine, if a soft incoherent bed be met with, or if a great influx of water occur in any beds, iron cylinders are built into the shaft, to prevent either the incoherent matter or the water from falling into the mine below.

Tutmen—A Cornish term for miners who excavate any matter, either rock or vein stuff, at so much a fathom or so much a ton—those who work by piece-work.

Underlie—The inclination of a vein or fault from the perpendicular, the complement of the dip.

Vein Stone—The compact or uncrystallised non-metallic contents of a vein.

Vogh, or Vugh—An occasional cavity or hole in a vein.

Walls—The sides of a vein; when inclined, the one which, when the miner is in the vein, hangs over his head, is called the *hanging* or *top* wall, the one under his foot is called the *foot* or *ledger* wall.

Wheal—In Cornwall, mines are often called Wheals, a way of spelling the old Cornish name Huel, a mine.

Winze—In a vein-mine what a jackey-pit is in a coal-mine: a shaft not sunk from the surface, but in the mine, to communicate between the different levels. In a large vein-mine, however, they are numerous and necessary parts of the workings.

CHAPTER XV.

CONCRETIONS IN ROCKS.

In many rocks, aqueous, igneous, and metamorphic, there occur concretions of mineral matter, sometimes formed contemporaneously with the rocks in which they occur, sometimes the result of subsequent segregation. In the present chapter we are concerned not with the various hypotheses as to the origin of these bodies, but with the nature and occurrence of the concretions themselves. By far the most abundant and characteristic varieties occur in aqueous or sedimentary rocks. Those in the igneous and metamorphic rocks are, as a rule, much less frequent and less distinctly characterised.

I. Concretions in Aqueous or Sedimentary Rocks.

In Sandstones.—Many sandstones, on being broken open, show parallel concentric bands of colour, usually of a darker brown or darker red than the generality of the stone, extending from an inch to several inches from the surface of the block towards its interior. These bands of colour are usually confined to single blocks of the rock, but sometimes extend through two or three adjacent blocks, and in some instances through several distinct beds of sandstone. The most striking case observed by the author was on the south side of Flagstaff Point, Wollongong, N. S. Wales, where a fine-grained, thick-bedded, reddish or grey, slightly calcareous sandstone, showed concentric bands of colour, some of which extended through eight or ten beds, the bands being a foot in breadth, and the space enclosed by them from twenty to thirty feet in diameter. The rock here, as is usually the case, showed a tendency to weather along these bands, and some of the smaller blocks, in which the concentric bands were confined to the single blocks, readily decomposed to a mere nodule, in the centre of which a fossil shell or coral often disclosed itself. The presence of small quantities of calcareous and ferruginous matter diffused through the sandstone is doubtless one of the conditions necessary for the production of these structures.

Many sandstones contain concretions of iron pyrites, varying in size from mere grains up to masses, sometimes at least as large as the fist. When such concretions are minute, and therefore not readily recognisable, they often escape notice, and the blocks in which they occur are dressed and inserted into the walls of buildings. Exposed to the weather they decompose, and dark stains of peroxide of iron soon disfigure the architecture. The Sable de Fontainebleau is a pure white sand. It is covered in some places by beds of a freshwater limestone called the Calcaire de Beauce. Water containing carbonate of lime in solution percolates through the sand, and deposits the lime, binding the sand either into globular concretions, or even into rhombohedral crystals, such as carbonate of lime ordinarily forms. Besides these smaller concretions, other large parts of the sand have been compacted together into a very hard white gritstone, which is extensively used as

a paving stone. This Grès de Fontainebleau forms picturesque crags and precipices, all the more striking, perhaps, from their contrast with the loose sand in which the masses of consolidated rock occur. In some cases the quartzose grains appear to be bound together by a siliceous cement, as if the percolating water had contained dissolved silica. This is obviously the case in one variety, a glittering rock being produced, greatly resembling ordinary quartzite, only more white and lustrous; this variety is called "Grès lustrée."

The Grès de Beauchamp consists of similar locally consolidated and semi-concretionary lumps of sandstone, occurring here and there in loose sand. In parts of the north of France these lumps of gritstone are discovered by "sounding," or piercing the loose sands with an iron rod,* and they are then extracted and broken into square blocks, and used for forming the roads of the country.

In Shale and Clay.—These are more numerous and important than those in sandstones. In some cases indurated shales assume a globular or concretionary structure, without any very striking difference, except that of form, being apparent between the spheroids and the adjacent shales (Fig. 119). Sometimes a single concretionary mass occurs, having a spheroidal, lenticular, or other form, sometimes

Fig. 119.

Sketch of Coal-measure shale weathering into spheroids, in a railway cutting near Mallow, County Cork, taken from the Explanation of Sheet 175 of Maps of Geol. Survey, Ireland.

solid throughout, and showing no tendency even to decompose in concentric coats, sometimes exhibiting such a tendency in a marked manner, the hard central portion being of small size compared with the original ball, sometimes even with the concentric coats detached before the nodule is broken, so that the central balls are heard to rattle when the detached concretion is shaken.

A remarkable instance is shown in Fig. 120, of a lenticular nodule embedded in

* According to Mr. Whitaker, greyweather blocks are found in the same way in the "brick earth" on the Chalk Hills, near High Wycombe. See *Geol. Surv. Memoirs*, sheet 7.

coal-measure shales of the County Clare, and enclosing part of a small layer of fossil shells, which extends for many yards beyond it on each side, as shown by the line A B. The nodule might be called a very *lean* clay ironstone, or one in which the proportion of ferruginous matter is insignificant. In some cases the whole mass of these shales assumes a nodular concretionary structure through a thickness of several feet, one larger spheroid often enclosing several smaller ones, as shown in Fig. 119.

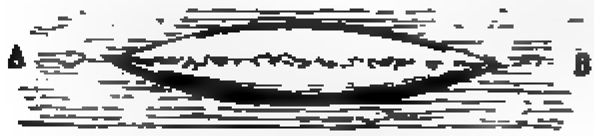

Fig. 120.
Lenticular nodule, developed along a line of fossil shells (A B).

The *Clay-ironstones*, which have been so largely the source of the British manufacture of iron, give us striking examples of this nodular concretionary structure, since, while they occur in regular beds, such as we can suppose to have been separately deposited as beds of clay ironstone, in the shape in which we now find them, they also, and most frequently, form layers of irregular concretionary nodules in shale or clay. These concretions are sometimes of very small size, so as to be called Pins or Pennystones, and other similar designations, sometimes they are large spheroidal masses of several inches, or one or two feet, or, more rarely, even five feet in diameter. The larger masses generally show irregular angular (see Fig. 121) cavities in the centre, sometimes quite empty, at others more or less full of spar, of carbonate of lime, or carbonate of iron, and not unfrequently with small crystals of blende (sulphide of zinc), or, more rarely, of galena (sulphide of lead). The size of these cavities generally increases towards the centre of the mass, the outer coat of the nodule being quite untraversed by any veins or fissures. The reason of this is apparently that consolidation occurred first in this outer envelope, the spheroidal form of which resisted all farther contraction, and that the farther shrinkage of the interior was directed towards this outer envelope, so as to leave vacant spaces, some of which were afterwards more or less filled up by the crystallisation of minerals that gained access to them in a state of solution.

Fig. 121.
Nodule, either an ironstone ball or a Septarian stone.

Some clay ironstones exhibit another concretionary form, called "cone in cone," as the seam of ironstone breaks into conical forms with the bases of the cones at top and bottom of the seam, and their apices pointing inwards towards each other. The surfaces of these cones are corrugated by small horizontal fretted wavelets, or ridges, rather resembling those on the outside of some stalactites, and each cone is concentrically enveloped by several coats, the surface of each being similarly corrugated.

Some coals also exhibit a curious structure in the interior, somewhat analogous to this, showing, when parted, a series of narrow winding corrugated ridges and furrows, about an inch wide and deep, fitting closely into each other till separated with some little force.

There occur concretionary *Septarian* nodules, sometimes two or three feet in diameter, in the clay under London, and other places, in which carbonate of lime plays the part which carbonate of iron does in the clay ironstones, the irregular internal fissures being formed in a similar manner, and filled up by crystalline calc-spar.

Iron Pyrites, or bisulphide of iron, occurs abundantly in some argillaceous rocks, especially in clay slates, in regular crystalline forms, which have obviously been assumed by the mineral since it was enclosed in the rock. These are sometimes single crystals, sometimes nests of such crystals two or three inches in diameter. Groups of cubical crystals, each an inch across, occur near Catalina, in Newfoundland, and are known as catalina-stone, firmly embedded in a green siliceous slate-rock. These crystals have evidently not been formed in a previously existing cavity, such as those which are known as "drusy cavities," but were produced in the solid rock by the interchange of place between one kind of mineral matter and the other kind, and the assumption of a regular crystalline form by the later mineral.

Phosphatic nodules occur in some clays, and also in sandstones and limestones, even as ancient as the Lower Silurian period. In the clay known as the Gault, and in the Chloritic Marl, lying at the base of the chalk of Cambridgeshire, etc., large numbers of nodules occur, containing, it is said, about sixty per cent of phosphate of lime. They are believed to be of coprolitic origin. In the Lower Silurian limestones and sandstones of Eastern Canada, similar nodules occur, often charged with fragmentary shells, and containing about forty per cent of phosphate of lime. These are sometimes an inch thick, and two inches long, contain embedded quartzose grains, and, when heated, give off strongly ammoniacal water, with the odour of burnt horn.*

In Limestones and Dolomites, the most striking and frequently-occurring concretions in limestone rocks are those of a siliceous character, such as the flints in chalk, and the masses of black and white chert in carboniferous and other limestones. Chalk flints occur as rounded nodular masses, of very irregular and some-

Fig. 122.

Sketch of some beds of limestone containing nodules of white chert, at Middleton Moor, in Derbyshire, in which the irregular and fantastic shapes assumed by these nodules are well exhibited, as also their likeness to flints in the chalk.

times fantastic shape, and of all sizes, up to a foot in diameter. They are commonly white outside, but internally are of various shades of black or brown, sometimes passing into white. They have sometimes concentric bands of black

* Sterry Hunt, in Logan's *Geology of Canada*, 462 and 758. These Canadian nodules are also probably coprolitic. They contain shells of *Lingula*, a brachiopod the shell of which, as Sterry Hunt has shown, contains in its fixed residue, left after calcination, more than 85 per cent of phosphate of lime.

and white colours internally, and exhibit markings derived from organic bodies round which they have often been formed. Flint occurs in the Chalk, not only in nodules, but also in seams or layers, sometimes short and irregular, sometimes regular, over a distance of several yards. These seams vary from one-tenth of an inch to four inches in thickness, and are commonly black in colour.*

Almost all large masses of limestone have their flints or siliceous concretions. These are frequently called *chert*, as in the carboniferous limestone, where the nodules and layers of chert exactly resemble the flints in the chalk. Even the tertiary limestones around Paris have their flints, the menilite of that locality being nothing but a siliceous concretion, found in the Calcaire St. Ouen, and possibly other places. Pure siliceous concretions occur even in the fresh-water limestones and gypsum beds of Montmartre.

Fig. 123.

Part of a seam of black chert in the limestone near Dublin. These seams, like those in chalk, are sometimes quite regular for some distance, and then either suddenly terminate, split up, or are subject to other irregularities like those in the figure.

The Chalk, however, in many places contains curious concretionary nodules of iron pyrites, sometimes as big as the fist, of a spheroidal form, and having internally a radiated structure. Two such nodules are sometimes connected by a cylindrical stick, so as to look at first like a leg-bone, these nodules always showing throughout a radiation from the centre to the surface, which proves that they are formed in the place in which they are embedded, and are not extraneous masses rounded by mechanical transport.

Dolomite or *Magnesian Limestone*, when it occurs in mass, has often a tendency to assume various nodular and concretionary forms, sometimes like a bundle of small twigs irregularly compacted together, sometimes like a heap of musket-shot, or bunches of grapes, or cannon-balls piled irregularly on each other. When they are like grapes they are then called *botryoidal* concretions. Cliffs showing these various forms may be readily examined near Sunderland, where the rock might often be mistaken for a conglomerate formed of rolled pebbles and rounded blocks, if the concretionary origin of the balls were not proved partly by their generally

Fig. 124.

Dolomite or Magnesian Limestone, showing concretionary structure. From the cliffs near Sunderland; the balls are three to six inches in diameter.

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* See *Geol. Surv. Memoirs*, sheet 13, p. 20.

having internally a radiated structure, but more strongly by the occurrence of lines of lamination running equally through the mass of the rock, and the balls included in it, as shown in Fig. 124, where, however, these horizontal lines of lamination are made a little too prominent in the balls and not quite enough so in the rock. These lines of lamination show that the rock was originally formed by the deposition of successive layers, the radiated globular form being subsequently assumed by parts of it.

In Rock-salt and Gypsum.—These deposits, from their purely chemical formation, might be expected to exhibit these concretionary forms. Great concentric circles of crystalline salt may be seen in the roof of the large salt-mines near Nantwich in Cheshire. Gypsum frequently occurs as mere veins and concretionary or crystalline masses, and even where it has been originally deposited in regular beds, or layers of minute crystals, that arrangement is apt to be disturbed by a subsequent modification into larger crystalline plates of selenite. Instances of this may be observed in the quarries at Montmartre, near Paris, where one or two beds, six or eight inches in thickness, consisting of thin layers of minute crystals of gypsum, are sometimes, for a space of several yards, traversed by perpendicular plates of selenite, through which the original layers may be distinctly traced.

In one observed example all the beds were horizontal, and the layers of small crystalline grains were quite parallel to the stratification; but, in the beds above mentioned, large tabular crystals and broad flakes of selenite, of rather irregular form, had struck directly across the bed, more or less nearly at right angles to it, the original horizontal lamination not being obliterated, but being in some places waved, as if slightly disturbed by the formation of the crystalline plates, the angles of these waves having evident relation to the faces and angles of the superinduced crystalline plates. This formed a good case of a molecular change of structure having taken place in the mass of the rock subsequently to its formation, like that before mentioned as occurring in the spheroidal concretions of magnesian limestone, and in the structure of stalactites and the limestone of coral reefs. It yet remains for the chemist to explain to us the exact method of operation by which these changes are produced.

Fig. 125.

a. Layers of small crystalline granules of gypsum.
b. Crystalline plates of gypsum, traversed by the faintly seen and displaced original layers of granules. These lines are not sufficiently oblique in the woodcut; on the faces of some of the crystals they form angles of 35° with the plane of the beds.

Large twin crystals of selenite also occur in the London and other clays; sometimes several inches across, and prove the relative motions of particles, both of the clay to make room for the gypsum, and of the gypsum that was originally dispersed through the surrounding clay.

It seems that when one mineral substance is diffused in comparatively small quantity through the mass of a rock, there is often a tendency in that diffused mineral to segregate and concentrate itself upon particular points, and this movement seems to have taken place equally from all sides, independently of gravitation, or at least only modified, but not controlled by it.

II. Concretions in Igneous Rocks.

As already remarked, the concretionary structure is less characteristically developed in Igneous than in Aqueous rocks. When it occurs in the former it is sometimes due to the peculiarities in the cooling and crystallisation of the rock, and therefore *congenital* or synchronous with the formation of the rock itself, as in the case of the drusy cavities of granite. Sometimes it arises from subsequent internal changes and re-arrangements in the rock, as in the amygdaloidal kernels in trap-rocks.

In Granite.—Many granites, though tolerably uniform in their texture, present numerous patches where the component minerals have formed much larger crystals round irregular cavities, wherein are found also other minerals which either do not occur at all, or only rarely, in the main body of the granite. In these "drusy cavities" the minerals are much more perfectly crystallised than in the general mass of the rock, and these are likewise the receptacles of the best topazes, beryls, cairngorms, and other gems which occur in granite.

It is not uncommon in some granites to meet with more or less angular pieces of a dark micaceous rock from less than an inch to several inches in length. They are frequently to be observed with no very sharp boundary lines, but rather to shade into the surrounding granite. They resemble somewhat in their form and mode of occurrence the "clay-galls" of some sandstones,* and may possibly have had originally a similar origin, but subsequently metamorphosed along with the rock in which they were imbedded.

In Trap-Rocks.—The globular structure revealed in many doleritic rocks by the process of "weathering" has been already described,† and the remarkable orbicular diorite, or Napoleonite of Corsica, consisting of an aggregate of spherical bodies, has been referred to in the description of rocks.‡

The most important concretions found in trap-rocks are those which fill up the amygdaloidal cavities. These cavities, though sometimes empty, are most frequently filled wholly or partially with some mineral or minerals which have been subsequently introduced into them. The nature of the infilling substance depends much upon the nature of the rock itself, for the student will find that in most cases the infiltration of mineral matter into the empty cells has been one result of the decomposition of the rock in which these cells exist, and hence, that wherever the cells are, or once have been, filled, the rock round about them is sure to be much decomposed. A strongly marked amygdaloid, therefore, will be found to contain its kernels in a more or less decayed base. In doleritic rocks, where labradorite has been acted on by percolating alkaline water, the production of zeolites has taken place,§ and our finest zeolites are found in the great doleritic plateaux of Antrim and the Inner Hebrides. The cavities are either filled entirely, as happens characteristically with heulandite and stilbite, or lined with crystals, the latter form being that in which the finer specimens of apophyllite, chabasite, etc., occur. Instead of zeolite, the cavities may be lined or filled with a purely siliceous substance. Thus, a coating of crystals of quartz often encloses an empty interior, or the walls of the kernel are lined with concentric layers of jasper, agate, chalcedony, which often fill the entire cavity, or allow the centre to be occupied by some crystallised quartz. It is from these amygdaloidal kernels that our "pebble" ornaments are chiefly obtained. In other cases, instead of a purely siliceous infiltration, we have one of a hydrous magnesian silicate, as chlorite, serpentine, steatite, or delessite. It often happens that such a silicate merely coats the cavity as a thin lining, the rest being filled up with some other mineral,

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* See *ante*, p. 127. † See *ante*, p. 182. ‡ See *ante*, p. 113.

§ The conversion of the felspars into zeolites, or hydrated felspars, is explained at pp. 85-87.

and when the kernel falls out of the rock it is found with the green chloritic or other coating covering its exterior.

In trap-tuffs concretions occur much as they do in some forms of ordinary sedimentary rock. Nodules of clay ironstone are found sometimes among the greenstone-tuffs of the carboniferous formations of central Scotland. Calcareous nodules likewise occur, as in some of the Welsh tuffs. The calcareous concretions in schalstein may likewise be alluded to.

III. Concretions in Metamorphic Rocks.

As concretions are so frequently themselves a product of a partial metamorphism or change of the mineral characters of rocks, we might reasonably expect to meet with them in the rocks that are distinctively termed metamorphic. Accordingly, we find that in gneiss, mica-schist, and in the rocks already described under the head of "Metamorphic Porphyries," there has been often a tendency to the segregation of minerals in irregular concretionary patches. Lumps of hornblende, not regularly crystallised, but full of intermixture with other minerals, occur in the oldest or Laurentian gneiss of the north-west of Scotland. In a similar way we meet with groups of crystals, or rather crystalline concretions, of felspar both in gneiss and mica-schist. Quartz is a common constituent of the irregular lumps which have been segregated in these rocks. The process of metamorphism appears to have been greatly modified by the varying nature of the materials upon which it had to operate. Where there were original fragments or lumps of material, differing markedly in composition from the surrounding rocks in which they lay, they may have given rise to a distinct new crystalline nucleus. There has likewise been a strong tendency in the different minerals, as quartz, orthoclase, hornblende, etc., to gather together in patches or concretions, as well as in those layers or folia which distinguish the foliated rocks.

II. GEOLOGICAL AGENCIES, OR DYNAMICAL GEOLOGY.

SECTION I.

UNDERGROUND AGENCIES.

CHAPTER XVI.

FORM AND INTERNAL CONDITION OF THE EARTH.

IN the foregoing part of this Manual we have been concerned simply with the record and description of the composition, texture, structure, and mode of occurrence of minerals and rocks, or with what is termed geognosy; a consideration of the agencies involved, and of the explanatory theories which have been proposed to account for the appearances described, have been reserved for this place. We now propose to present to the student as succinct a resumé as possible of the various agents and processes which have been concerned in the production of the rocks and rock-structures with which he has already become acquainted. We shall first consider the changes which are in progress beneath the surface, within what is called the crust of the earth, and many of which affect that surface in the most momentous way. We shall then proceed to the discussion of the agencies which are at work above ground, and show the changes which they bring about. Lastly, we shall give an outline of the results achieved by the combined action of subterranean and superficial forces in modifying the surface of the earth.

Form of the Earth.—The earth is an oblate spheroid, the polar diameter being 7899·60 statute miles, and the equatorial, 7926·05,* or $26\frac{1}{2}$ miles longer. The equatorial radius, therefore, is about $13\frac{1}{4}$ statute miles longer than the polar radius, or, in round numbers, 70,000 feet. If, therefore, we imagine a true sphere to be described within the earth, the radius of which shall be equal to the polar radius, the sur-

* These numbers are those deduced by M. Bessel. It has been lately stated, on good authority, that different equatorial diameters vary in length to the extent of one or two miles, but these slight variations will not affect the reasoning in the text.

face of that sphere will coincide with the actual surface of the earth only about the poles, but will sink beneath the actual surface, as we recede from the poles, gradually and regularly, till it is 70,000 feet deep under the equator (see Fig. 126).

Let Fig. 126 represent a section of the earth through the poles P P, and the centre *c*, the line P P being its polar diameter, and the line E E its equatorial diameter, and let it be drawn on a scale of 2600 miles to the inch. Then, if an inner circle be drawn one-tenth of an inch inside P P, that will represent a depth of 260 miles, and the circle P *e* P *e*

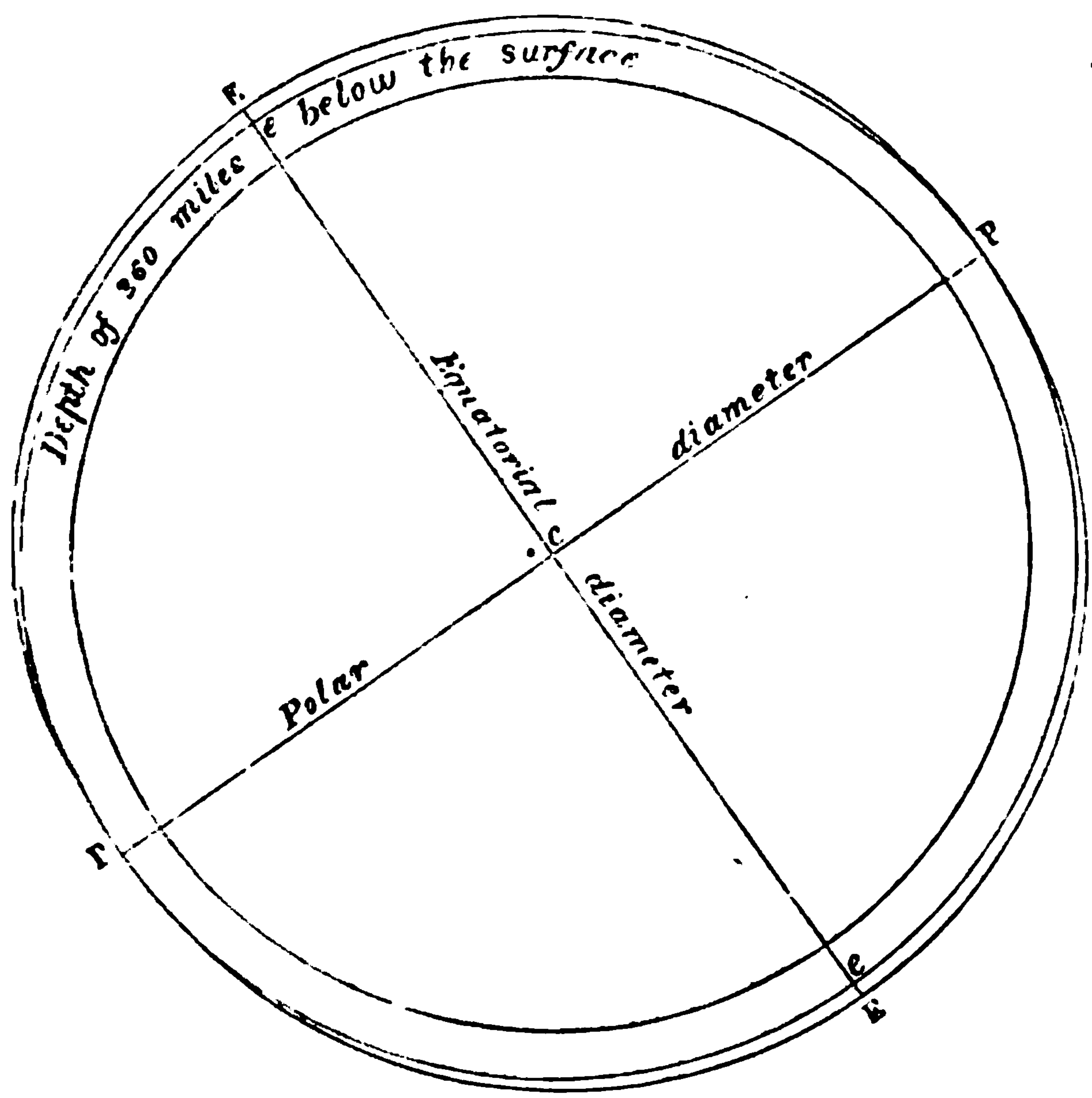

Fig. 126.

will represent the circumference of the supposed internal sphere drawn on the polar radius *c* P. The curved outer line P E P E will then represent the actual surface of the earth protuberant beyond this internal sphere, but this is not drawn to scale. The space between the letters *e* E on each side ought to be only one-twentieth of the space between P and the inner circle, whereas it is drawn nearly as $\frac{1}{4}$, since a twentieth of that space would not be visible to the naked eye. Making allowance for this necessary distortion, the outer line of the figure will represent the surface of the earth bulging at the equator $13\frac{1}{4}$ miles beyond the

supposed internal sphere. This equatorial protuberance may, in fact, as Professor Hennessey once remarked to the author, be likened to a great mountain mass resting on the supposed internal sphere, with a base equal to the whole surface of that sphere, and rising to a height of 70,000 feet above it under the equator. The upper surface of the sea, or *sea-level,* will form the true mean or symmetrical surface of this protuberant shell. The surface of the solid crust of the earth rises irregularly above the *sea-level* into dry land, and sinks irregularly below it to form the ocean-bed. The mass of the dry land, however, is so small compared with the bulk of this protuberant shell, as to be quite insignificant, even when we take into account such a boss as the table-land of Thibet, with a mean height of 10,000 or 12,000 feet, and a diameter of 600 miles, or such occasional pinnacles as the Himmalayah Mountains, of which the loftiest, Mount Everest, rises 29,000 feet above the sea-level. The depths of the ocean are doubtless greater than the heights of the land, but it may very well be doubted whether much of the surface of its bed, except perhaps in the Polar regions, sinks below the protuberant shell of the earth down to the surface of the supposed internal sphere before mentioned.

The irregularities in the surface of the earth are then merely *irregularities in its protuberant shell,* and they are largely compensated for by all their lower hollows being filled with water, up to a height which must certainly be considerably above the mean level of these irregularities.

Stability of the Earth's Axis.—This protuberant shell, consisting partly of earth and partly of water, provides for the stability of the earth's axis and the permanence of its general form. The actual circumference of the earth's equator is about eighty-three miles greater than that of the circumference of the true sphere enclosed in it, and its movement of rotation is correspondingly more rapid than that of the surface of that sphere. If, therefore, any disturbing action, either internal or external, tended to cause the earth to rotate on any other axis than the existing one, it would have to overcome the resistance of the greater centrifugal force now residing in the equatorial protuberance of the earth, and transfer it to some other circumference. It seems difficult to imagine any cause capable of this, but even if it existed, unless the earth immediately adjusted its form to its new motion, and transferred its protuberance to the new equator, the disturbance could only be temporary, and the earth would immediately begin to swing back, so as to rotate upon its shortest diameter as an axis, and its largest circumference as an equator.

Ever since the earth assumed its present form of an oblate spheroid, the position of its axis has probably remained within it unchanged, and the points on its surface now occupied by the north and south poles

have continued to be its poles. Whether the present axis of the earth always pointed to the same point of the heavens (making allowance for merely periodical motions, such as that of nutation), or whether it was always inclined $23\frac{1}{2}°$* from the pole of its orbit, and the equator correspondingly inclined to the ecliptic, is altogether another question, to which there seems to be nothing in the internal constitution or external form of the earth, calculated to give an answer.†

Internal Temperature of the Earth.—It is, however, very remarkable, that the form of the earth, as above described, is said to be almost exactly that of a spheroid of rotation; that is the form which the earth would have assumed supposing it to have been once a fluid or pasty mass revolving with its present velocity. That the earth has this form, certainly raises a strong presumption in our minds that it was once fluid or pasty. We may arrive at some conclusions on this subject from the following considerations relative to the temperature of the earth's interior :—

a. Volcanoes.—The phenomena of volcanoes pouring out molten rock on all sides of the globe, assure us that large parts at least of the interior are, from some cause or other, so heated as to render the materials of solid rock perfectly fluid. Extinct volcanoes show us that this was the case formerly with other parts of the globe, where the action is not now apparent. Other masses of igneous rock, all connected with actual lavas by a regular chain of gradation, are found to have proceeded from the interior, up to or towards the surface, even where there is no appearance now, and perhaps never was any, of actual volcanic vents upon the surface. This almost universal appearance at the surface of once molten rock, proceeding from the

* Astronomers inform us (see Herschel's *Outlines of Astronomy*, chap. xii., art. 680), that the obliquity of the ecliptic to the equator is now diminishing at the rate of 48″ in a century, but that, after the diminution has reached a certain point, it will again increase, the amount of variation in their angle never exceeding 1° 21′.

If the ecliptic were actually to coincide with the equator, the result would be a great change in the climate of the earth, since there would be continual sunshine at the poles, and for a circle of 60 or 70 miles round them; no darkness greater than twilight in the major part of the arctic and antarctic circles; and equal day and night all over the rest of the globe.

† Several ingenious speculations as to changes of the earth's axis have been of late years put forward, since the publication of the last edition of this work. One of these, by Mr. J. Evans, attempts to show that a change in the position of the earth's axis of rotation, and a consequent change of latitude in all places on its surface, might have been produced by the elevation of mountain chains on that surface. If the earth were a perfect sphere, doubtless the smallest additional protuberance would affect its balance. With its present protuberant shell we cannot imagine that any new mountain chain could do so to any perceptible degree, unless it were one running east and west, in about lat. 45°, and rising to a mean altitude far greater than that of any of our present mountain chains. Our existing mountains are merely like specks of dust on an artificial globe, and our deepest oceans like flakes chipped out of its varnish, and altogether too insignificant to produce any appreciable cosmical effect.

interior of the earth, proves that there must be some general source of heat in that direction.

b. Temperature of deep Mines and Wells.—As a matter of direct observation, it is found that in all deep mines the temperature of the rock increases as we descend, at the rate of 1° of Fahrenheit for every 50 or 60 feet of descent after the first hundred. This is the case in every part of the globe, and in all kinds of rock. Numerous observations have been made, with all possible precautions against mistake, and though the results vary in amount, they all agree in giving an increase of temperature. In the deep coal-pit, sunk at Dukinfield, near Manchester, at a depth of 2151 feet, the temperature is constantly 75° Fahrenheit, while the constant temperature at a depth of 17 feet, was only 51° Fahrenheit. This gives an increase of 1° Fahrenheit for every 89 feet only, or less than the average.* Mr. Henwood long ago made an elaborate series of experiments on the temperature of the deep mines in Cornwall, which showed that at a depth of 1200 feet the temperature of the slate was constantly 84° Fahrenheit, and that of the granite 81°. Deep wells, such as the deep Artesian well of Grenelle, at Paris, are always found to have a high temperature. At Grenelle, the water brought from a depth of 1798 feet has a constant temperature of 81°·7 of Fahrenheit, while the mean temperature of the air in the cellar of the Paris Observatory is only 53°. Very accurate and careful observations were made by M. Walferdin on the temperature of two borings at Creuzot, within a mile of each other, commencing at a height of 1030 feet above the sea, and going down to a depth, the one of 2678 feet, the other about 1900 feet. The results, after every possible precaution had been taken to ensure correctness, gave a rise of 1° Fahrenheit for every 55 feet, down to a depth of 1800 feet, beyond which the rise of temperature was more rapid, being 1° Fahrenheit for every 44 feet of descent.† Hot springs are usually found to proceed from great faults or fissures which penetrate deeply into the crust of the globe, and are sometimes met with in deep mines, proceeding from still greater depths.

c. Specific Gravity of the Earth.—Experiments formerly made on the attraction exercised by the mountains of Schehallion and Mt. Cenis, and lately on the deflection of the plumb-line at Edinburgh, as calculated by the Ordnance Survey, under Col. Sir H. James,‡ as well as experiments with leaden balls, on the torsion balance, by Cavendish and Mitchell, and more lately by Mr. Baily, give a specific gravity for the whole earth, varying from 5 to 5·6. Experiments on the difference in the times of oscillation of a pendulum at the bottom and

* See an account of Mr. Fairbairn's observations on this mine, in Mr. Hull's *Coalfields of Great Britain.*

† *Cosmos*, May 15, 1857.

‡ *Phil. Trans.* for 1856, vol. cxlvi. p. 591.

top of a deep coal-mine at Harton, by the Astronomer-Royal, give as much as 6·56 for the mean density of the earth.* We may confidently say, therefore, that the earth has a specific gravity of about 5 or 6. Now, the specific gravity of granite varies from 2·6 to 2·9 ; that of basalt is about 3·0 ; that of rock in general is from 2·5 to 3·0. The earth, therefore, is at least twice as heavy as it would be if made of any known rock, such as that rock appears at the surface. The pressure of gravity, however, would render any such rock, as granite for instance, much more than twice as dense as it is at the surface, long before it reached the centre. According to Leslie, water would be as heavy as mercury at a depth of 362 miles, air as heavy as water at 34 miles. At the centre of the globe steel would be compressed into one-fourth of the dimensions it has at the surface, and most stone into one-eighth, if the law of compression be supposed to be uniform from the surface to the centre. We should therefore expect that the whole earth, if its substance be homogeneous, and at all resembling granite for instance in constitution, would have a much greater specific gravity than 5 or 6, if it were not for some expansive force in its interior counteracting the pressure resulting from gravitation. We know of no such force except that of heat.†

There can therefore be no doubt that the earth has a high internal temperature of its own, altogether independent of any heat it may receive from the sun or other extraneous sources, and that it consists of a cool envelope surrounding a heated interior. This outer envelope is called *the Earth's Crust*, without now necessarily implying that it is actually a true rind or crust surrounding a molten interior.

Question as to Fluidity of central part of Globe.—If we suppose that the rate of increase observed in mines and deep wells is continued indefinitely into the interior, it would follow that, at a depth of 10,000 feet beneath the British Islands, all water must be as hot as boiling water is at the surface, or 212° F. At a depth of about 20 miles the temperature of all parts of the globe would be 1760° F. ; and at 50 miles would be 4600° F. Now, the heat of a common fire is calculated at 1140° F. ; brass melts at 1860° F. ; gold at 2106° F. ; and platinum at 3080° F.

It would then appear that, if the increase of temperature be regular, all substances that we know at the surface must be molton at a comparatively slight depth ; at about one-fifth of that, for instance, indicated by the inner circle in Fig. 126. This fusion, however, does not

* *Phil. Trans.* vol. cxlvi. p. 355.

† This argument, if it stood alone, would not perhaps be of any great value, since it is open to anybody to deny the homogeneity of the interior of the earth, and to suppose that it is likely to contain a larger proportion of metal in the interior than near the surface, and that it may be a hollow spheroid. The fact of a high internal temperature, however, may be held to be sufficiently proved by the two preceding arguments.

follow as a necessary consequence, since we do not know how far towards the interior the increase of temperature proceeds at anything like the rate which it does at the slight depths to which we have penetrated. Neither do we know how far the influence of increased pressure may operate to keep matter solid, even when raised to temperatures that would be more than sufficient to render them fluid if it were communicated to them at the surface of the earth.

Water, at a height of 12,000 feet above the surface (as on the Peak of Teneriffe), cannot be made hotter than 190° F., since it boils, that is, it becomes steam, at that temperature. At the level of the sea it requires to be raised to 212° F. before it passes into steam; at the bottom of a deep mine the increased pressure of the atmosphere would keep it in the liquid state up to 214° F. or higher; and so we may well suppose that at great depths water might be raised to 500° or 600° F., perhaps, and still remain water.

What is true of a liquid passing into a vapour may be also more or less true of a solid passing into a liquid state, although less is known of the relations between increase of temperature and of pressure in the latter case. It seems likely, however, not only that the melting points of solids should be largely affected by variations in the pressure to which they are subjected, but that different solid substances should be affected in a different ratio. If this be the case, it will follow that we cannot arrive at any definite conclusion as to the thickness of the solid crust of the globe from the consideration of the internal temperature only; and also seems to follow, that at some depth there must be a stratum of very high temperature, in which the materials may be solid in some parts and fluid in others, and that this stratum of passage from the wholly solid to the wholly fluid state may be of indefinite thickness, so that relative motion in the matters composing the interior of the earth may be impossible.

It has been shown, by the researches of Sir William Thomson,* that the earth, like the other members of the solar system, has for millions of years been losing, by dissipation into space, a considerable proportion of the energy originally stored up in its mass; and that, from the known general increase of temperature in the earth downwards, we may approximate to an estimate of the date at which the surface of the earth became sufficiently cooled and solid for the evolution of geological phenomena. The fact that there is such a downward increase of temperature implies a continual loss of heat from the interior, and consequently also (since the upper crust does not become hotter), a secular loss of heat from the whole earth. If this loss of heat has continued for a vast indefinite period, it is probable that there was a time when the body of the earth was an incandescent

* *Trans. Roy. Soc. Edinburgh*, xxiii. 157.

liquid. Applying a solution of Fourier, Sir William Thomson estimates that the superficial consolidation of the globe, or the "consistentior status" of Leibnitz, "could not have taken place less than 20,000,000 years ago, or we should have more underground heat than we actually have, nor more than 400,000,000 years ago, or we should not have the least observed underground increment of temperature." More recent consideration of the subject inclines him to place the date of the "emergence" of this "status" about 100,000,000 years ago.* All geological history would require to be comprised within that period. Assuming, with considerable probability, that the earth, previous to the beginning of that period, consisted either of a solid nucleus, surrounded with a deep ocean of melted rocks, or was liquid to the centre, and that it was left to cool by radiation into space, he argues from the thermo-dynamic law of freezing, and from that connecting temperature and pressure, that it is most consistent with the present state of our knowledge to infer that the solidification of the globe proceeded from within outwards, and that there could be no permanent incrustation all round the surface till the whole globe was solid. In this conclusion he agrees with that previously arrived at by Mr. Hopkins, with whom also he coincides in suggesting that within the generally solid globe there may still exist irregular, comparatively small (though, of course, if measured by miles, extensive), spaces of liquid. "In the honeycombed solid and liquid mass thus formed," he adds, "there must be a continual tendency for the liquid, in consequence of its less specific gravity, to work its way up, whether by masses of solid falling from the roofs of vesicles or tunnels, and causing earthquake shocks, or by the roof breaking quite through when very thin, so as to cause two such hollows to unite, or the liquid of any of them to flow out freely over the outer surface of the earth; or by gradual subsidence of the solid, owing to the thermo-dynamic melting, which portions of it, under intense stress, must experience." He considers that, even with this honeycombed structure, the interior of the earth at present "is, on the whole, more rigid certainly than a continuous solid globe of glass of the same diameter, and probably than one of steel.†

* *Trans. Geol. Soc. Glasgow*, vol. iii.

† The student should consult on this subject the papers of Mr. Hopkins, *Brit. Assoc. Report*, 1847, *Phil. Trans.* 1839; *Phys. Geol. Researches*, 1839-42; and by Professors Haughton and Hennessey, *Trans. Roy. Irish Acad.* See also the essay by M. Delaunay, *Chemical News*, Oct. 1868, and *Geol. Mag.* v. 507. It should be mentioned that Sir William Thomson relied upon the data arrived at by Bischof regarding the contraction of rocks in passing into the solid state, which, in the case of granite and other rocks, was said by the German chemist to amount to about 20 per cent. Doubts, however, have been cast on the validity of these data. It is certain that a bar of solid iron actually floats on the surface of the melted metal. See D. Forbes, *Geol. Mag.* iv., *Chemical News*, Oct. 1867; Sterry Hunt, *Chemical News*, xv., 315; *Proc. Roy. Inst.*, May 31, 1867; Pratt, *Proc. Roy. Soc.*, 1870.

Exciting Causes of Disturbing Action on Earth's Crust.—If the idea of an intensely heated, somewhat honeycombed centre, abounding in large vesicular spaces of still liquid matter, and covered with a comparatively thin cool outer portion or crust, be a true conception of the condition of our globe, it is obvious that we have an abundant source of igneous action and of mechanical movement in different parts of that crust, from time to time, provided we can admit of local exciting causes producing an occasional determination of the internal heat towards certain spots or lines of the surface.

What is the exact nature of these local exciting causes is a question to which no perfectly satisfactory answer has yet been given. The suggestion of Sir William Thomson has just been given. Another, but one which may quite well be taken as a concomitant of the former, is, that water gaining access from the surface to the reservoirs of incandescent matter in the interior, generates explosions of steam, by which earthquakes and volcanic eruptions are produced. Sir Humphrey Davy proposed, and Dr. Daubeny supported, a hypothesis that the oxidation of the metallic bases of the earths and alkalies, by the access of air and water, produce the local intensity of heat, by which subterranean disturbances are caused.*

The solution of this problem, if it is ever to be obtained, will still require the united labours of the physicist and the chemist. In the meantime, the student may pass from the region of speculation as to what may be the nature of the earth's interior, and the causes of the movements there, and turn his attention to the results which geology proves to have been effected upon the surface, and upon the mass of the outer crust by the influence of the internal heat.

* See the papers quoted in the previous note; also Daubeny's *Volcanoes*, 2d Edit.

CHAPTER XVII.

MOVEMENTS OF UPHEAVAL AND DEPRESSION OF THE EARTH'S CRUST.

We may speculate as to the nature and origin of the movements which take place within the crust of the earth, but that such movements do take place is a fact of which we have many, and sometimes disastrous proofs. Their existence at the present time is shown by the slow elevation of land in some places, or its slow submergence in others; by earthquakes and by volcanoes. We shall consider these phenomena in the order now stated. But first of all it may be of use to prefix a few remarks, to show that in such movements as those which affect the relative levels of sea and land, it is the land which is moved up or down, and not the sea.

It is clear that all rocks which were formed at the bottom of the sea, and which are now dry land, must have gained their present situation either by the sinking of the surface of the sea, or by the uplifting of its bed. If, however, the level of the sea be materially lowered by underground movements in any one part of the globe, it must be equally lowered over its whole surface. But we find aqueous rocks on the summits of some of our highest mountains, and if these had been laid dry solely by the shrinking of the sea, without any movement in the solid crust of the globe, either on dry land, or beneath the ocean, we must suppose that a shell of water, several thousand feet in depth, has been removed bodily from the earth into another part of the universe. For if the quantity of water in the ocean remained the same, its general surface level could not permanently sink, unless there were a hollow made in the solid part of its bed for the water to sink into. Neither could its general surface level be permanently raised, except by the filling up of parts of its bed by the deposition of earthy matter; or else by a contraction of the capacity of its bed by the rising of the solid rock below it. If the quantity of water on the globe, then, remains the same, any permanent change in the level of the sea, even if it were an equal and uniform change all over the globe, could only be caused by a previous change of position in some of the solid parts of the crust of the globe.*

* See the original statement of this argument in Playfair's *Illustrations of the Huttonian Theory*, p. 441.

There are indeed circumstances of a cosmical kind, by which the relative levels of sea and land may be affected. Owing to the attraction caused by the accumulation of large masses of ice at the pole, the general level of the ocean might be raised in polar and diminished in equatorial latitudes.* Mr. Croll has likewise pointed out that in consequence of the diminution of centrifugal force owing to the retardation of the earth's rotation caused by the tidal-wave, the level of the sea must tend to sink at the equator and rise at the poles. This would not, however, necessarily, in the end, expose a larger amount of land at the equator, for the change of level resulting from this cause would be so slow that denudation might quite well keep pace with it, and diminish the area of land as much as the retreat of the ocean tended to increase it; while, as Mr. Croll has further shown, the denudation of the equatorial land and the deposition of the detritus in higher latitudes must still further counteract the effects of retardation and the consequent change of ocean-level.†

But while such general causes of change in the relative levels of sea and land require to be taken into account in any broad philosophical view of the geological economy of our globe, it is nevertheless true, that in the great majority of cases which come before us, where a change of level must have taken place, it is the land which has risen or sunk, and not the ocean. For all practical geological purposes, we may assume the sea-level to be invariable, and that the fact that rocks originally formed under the sea are now found as hills and mountains, is a proof that these rocks have been elevated. It is not so easy to prove the fact of depression, since the very act of the sinking of land below water removes the evidence that it was once above it. We may arrive at this conclusion in another way. We could not continue our observations upon stratified rocks very long, without perceiving that their beds are generally inclined to the horizon. Now, though it is true that in certain cases beds of stratified rock may be formed on a slope, these cases must be limited to small areas. A steep slope cannot be of indefinite extent, and could not have parallel beds deposited over its whole area if it were.‡ Whenever, then, we have very widely spread beds, maintaining an equal thickness and strict or approximate parallelism over a large extent of ground, we may feel perfectly sure that those beds when first formed were practically horizontal. If such beds are now found in an inclined position, they must have been moved since their formation, and *tilted*, either by being

* See Croll, *Phil. Mag.*, April 1866; *Ibid.*, June 1867; *Trans. Geol. Soc. Glasgow*, ii. 177.

† See Sir William Thomson's paper, in *Trans. Geol. Soc. Glasgow*, vol. iii. p. 223; Croll, *Phil. Mag.* for 1868, p. 382.

‡ See *Overlap*, *ante*, p. 237.

lifted up at one end or depressed at the other, or both ways. In many cases this motion has been very great, so that the beds rest at high angles with the horizon, and in some cases are absolutely vertical. Beds consisting of alternations of clay and sand, with thin seams of round pebbles, have been tilted up till they are now perpendicular (see Fig. 127). No one could look at a cliff exhibiting these facts, without feeling certain that in this case some internal force had acted upon previously horizontal beds, and tilted them into their present position.

Fig. 127.

Beds containing layers of round pebbles, which must, therefore, have been deposited horizontally, now in a vertical position.

From what has been observed to occur in our own days, and what we can see has taken place formerly, there appear to be two kinds of movement on the earth's crust. The one is a broad equable movement, of vertical elevation or depression, affecting large areas simultaneously, but not producing any sensible *tilt* in the beds; while the other is more local, and imparts to the beds not only a vertical elevation or depression, but an angular inclination different from what they had before.

The widely-spread vertical movement which affects the surface now may be merely the external symptom of the more deeply seated motion which *tilts* or *bends* the beds below. Such inclinations may never be given to beds near the surface except for very small distances, or, in other words, the greatest contortion and compression of beds may not have been accompanied by any more sensible change at the surface than a gradual elevation or depression of the land or sea-bed.

a. Slow Movements of Upheaval.

It has been ascertained that a number of wide areas of the earth's surface are at this moment slowly rising with respect to the sea-level. The Scandinavian peninsula, except a part of its southern end, is undergoing an upward movement, for, within the memory of man, sunken rocks have become visible, reefs have grown in size, shoals have been converted into dry land, and marks made on rocks, to test the rate of rise, are now found to be higher relatively to the sea-level than they were at first. The rate does not appear to be uniform over the whole

country ; in some districts it has been estimated at two or three feet in a century. The movement, if its present has been its average rate, must have been in progress for a very long time, for we find beds of sea-shells of living species at heights of 600 and 700 feet above the present sea-level.* Among other regions which are either now rising, or which have been but recently upraised, may be instanced the coast-line of Siberia for 600 miles to the east of the Lena, the coast of Smith's Sound, different portions of the borders of the Mediterranean, and, on the most marvellous scale, the western mountainous margin of South America.†

The proofs of elevation of land are furnished by—(1.) Observed changes in the position of works of human construction with respect to the sea-level. (2.) Similar changes in the sea-level relatively to rocks, reefs, etc. (3.) The position of sea-worn caves above the present limit of the waves. (4.) Rocks covered with shell-fish above the existing tide-mark. (5.) Lines of former sea-margins or *raised beaches.*

1. **Proofs from Works of Human Construction.**—If the upward movement is extremely slow, it escapes notice by even the maritime population of the country unless they have accurate sea-marks, as in piers and harbours, by which to measure it. If the rate were as much as six feet in a century, the inhabitants of the inland districts would not observe it at all, and to those along the coast it would be chiefly marked by the fact that the tide no longer flowed over spaces where, a few generations before, vessels were moored, and that old bulwarks and piers now rose higher than the limit reached even by the highest tides.

2. **Proofs from Raised Reefs and Rocks.**—The elevation of the land would become still further apparent from the fact that rocks and boulders, once half-tide marks, stood now beyond the tide-line ; that reefs, formerly covered at high-water, were now permanently dry ; and that sunken rocks now appeared where formerly they were never seen, even when the tides were at the lowest. In such cases, it would be plain that the change could not arise from any heaping up of materials on the land, so as to keep back the sea, but that the land must actually have risen.

3. **Proofs from Old Sea-caves.**—One of the results of the ceaseless abrading action of the waves is to drill lines of caves along exposed rocky shores. The conditions of this process will be noticed in a subsequent chapter. In the meantime, let us observe that such caves are formed only between tide-marks, and therefore form an excellent criterion of the relative level of sea and land. When, therefore, we find lines of these caves removed above the tide-line, and sometimes even along the

* See the evidence, fully given, in Sir Charles Lyell's *Principles of Geology.*

† Paper on Earthquakes and Volcanoes, by the present Editor, in Chambers's *Miscellany of Tracts.*

face of an exposed precipitous bank or cliff, we infer, without hesitation, that since the caves were excavated the land has risen, and that the amount of the rise is to be measured by the vertical distance of the floor of the caves above the level at which similar caves are being excavated now. Many caves of this kind, sometimes singly, sometimes in continuous groups, and even in long lines, are found along both sides of Scotland, at heights varying from eight or ten to more than a hundred feet above the present high-water mark.

4. Proofs from Barnacles, etc.—One of the most common features of the boulders and rocks between tide-marks is the grey crust of barnacles, limpets, etc., by which they are coated, and the holes bored in them by various mollusca. We know that these marine animals require to be washed daily by the sea, otherwise they die. Hence, when we meet with their bleached shells still adhering to cliffs and rocks which stand above the reach of the waves, we conclude, without hesitation, that the land has risen since these animals lived. Of course a single boulder or large block of stone crusted with the shells would not necessarily prove the uprise, for such a block, or even a great many of them, might easily have been thrown up by a storm. But when the solid cliff, or projecting rocks, rise above the sea-level, and retain the crust of shells and the holes which the boring shells made, the conclusion is forced upon us that the land has been upheaved.

5. Proofs from Raised Beaches.—Between tide-marks, at present, the sea is constantly engaged in producing sand and gravel, spreading these out upon the beach, mingling with them the remains of shells and other marine organisms, and sometimes piling them up, sometimes sweeping them away out into the deeps. The beach is a well-marked feature of every land which is laved by a tidal sea. When the land rises with sufficient rapidity to carry up this line of beach-deposits before they are washed away by the waves, they form a flat terrace, or what is known to geologists as a raised beach. The old high-water mark is then inland, its sea-worn caves become in time coated with ferns and mosses, the old beach forms an admirable platform, on which meadows, fields, and gardens, roads, houses, villages, and towns, spring up, and the sea goes on forming a new beach below and beyond the margin of the old one. Raised beaches abound round many parts of the coast-line of Britain. Some excellent examples occur in Cornwall and Devon.* The Scottish coast-line, on both sides of the island, is fringed with raised beaches, sometimes four or five occurring above each other, at heights of 25, 40, 60, and 75 feet respectively above the present high-water mark. Each of these lines of terrace marks a former lower level at which the land stood with regard to the sea, and the space between each of them represents the vertical amount of each suc-

* See Sir H. de la Beche's *Report on Geology of Devon and Cornwall*, p. 423, *et seq.*

cessive uprise of the land. Each terrace probably indicates its own lengthened stay at the sea-line, while the intervening slopes show that the land in its upward movement did not remain long enough at any intermediate points to give the sea time to form terraces. In other words, a succession of raised beaches, rising one over the other, above the present sea-level, points to a former protracted upheaval of the country, interrupted by long pauses, during which the level did not materially change.*

β.—Slow Movements of Depression.

It has been already remarked that when the land sinks beneath the sea-level, instead of rising above it, the fact is less easily detected, because the depression removes the evidence of the previous sea-margin. Nevertheless, partly by the direct evidence of experience, and partly by deductions from geological data, we have learnt that over vast areas of the earth's surface the crust is subsiding, and that both land and sea-bed are sinking at the present time, or have only recently ceased to do so. A depression is proved by—(1.) The rising of the sea over human constructions and objects of nature, the previous relative levels of which are known. (2.) Submerged forests. (3.) The existence of fjords. (4.) The development of coral-islands.

1. Proofs from Human Testimony.—Some care is required to distinguish between the results of mere erosion by the sea and those of actual depression of the level of the land. The mere encroachment of the sea upon the land, and the disappearance of successive fields, roads, houses, villages, and even whole parishes, does not necessarily point to a sinking of the land, for, as we shall find in a subsequent chapter, all this destruction of the coast-line is in progress in our own country, without any sensible change of level. If, however, the sea actually comes to wash over roads and buildings which it never used to touch, if old half-tide rocks gradually cease to appear even at low-water, and if rocks that were previously above the reach of the highest tide are turned into shore reefs, and skerries, and islets, we infer that the coast-line is undergoing a movement of depression.

In Scania, the most southerly part of Sweden, the seaport towns

* It may be well, however, to recall the student's attention to the fact already mentioned, that the level of the ocean in different regions may be affected by cosmical causes, and consequently that the proofs of elevation given in the text may certainly be in some cases explicable by the withdrawal of the ocean. For example, if during what is known as the glacial period an enormous ice-cap formed about the North Pole, its effect would be to draw towards it the waters of the ocean. The level of the sea would rise in the higher latitudes, and if this heightened level remained stationary long enough to allow of a beach-terrace being formed, the subsequent retreat of the sea consequent on the melting of the ice-cap would leave a line of raised beach on the re-emerging land. All such cosmical causes, however, could only affect wide areas of the earth's surface. The local character, in most cases, of the proofs given in the text is satisfactory evidence that they are correctly referred to movements of the land rather than of the ocean.

bear evidence that the land is there sinking. Streets, originally built above high-water mark, are now below it, and even old streets are found at a still lower level, showing that the subsidence has been in progress for a considerable time. A stone, the position of which had been exactly fixed by Linnæus in 1749, was found, in 1836, to be a hundred feet nearer the water's edge than it was eighty-seven years before. The west coast of Greenland, in like manner, is subsiding over a space of more than 600 miles. Ancient buildings on low shores and islets have been submerged, and the Moravian settlers have more than once had to remove further inland their boat-poles, the old poles remaining now under water.*

2. Submerged Forests.—The depression which carries down below the sea-level works of human fabrication, will of course involve in the same common fate the works of nature. As a general rule, indeed, the land, as it is brought down foot by foot within the influence of the waves, will be so far denuded and re-formed that comparatively slight traces of the terrestrial surface will survive to be carried down beneath the zone of tidal and wave-action, and there covered over with and preserved under marine deposits. Consequently, though we can prove many depressions to have taken place in past time, the actual proofs of former land-surfaces are comparatively rare. Now and then, however under favourable circumstances, as for instance in sheltered bays and estuaries, fragments of old land-surfaces remain still distinct under water. They consist of what are known commonly as "submerged" or "submarine forests," that is to say, groups of trees still partly erect, and with their roots still in their native soil. Sometimes beds of peat occur in similar positions, full of tree-stumps, hazel-nuts, branches, leaves, etc.

"Round the shores of Devon, Cornwall, and Western Somerset, a vegetable accumulation, consisting of plants of the same species as those which now grow freely in the adjoining land, is frequently discovered, occurring as a bed at the mouths of valleys, at the bottoms of sheltered bays, and in front and under low tracts of land, the seaward side of which dips beneath the present level of the sea."† This old land-surface is found to be very commonly covered with sand and silt, in which estuary shells are found, showing that the subsidence was gradual, the valleys first becoming estuaries, and then sea-bays. Similar submerged forests occur at different places along the more sheltered parts of the coast-line of Scotland.

The foregoing two kinds of evidence of depression are of such a nature as to require no special geological training to appreciate their force. The two remaining branches of proof, however, pre-suppose a certain amount of acquaintance with several parts of geological evidence and reasoning. Their full meaning and importance will be better

* Lyell's *Principles*, ii. 190-7.

† De la Beche, *Geological Report on Devon and Cornwall*, p. 420.

understood by the student when he has completed the perusal of this part of the Manual.

3. Evidence from Fjords or Sea-Lochs.—A fjord is a long narrow inlet of the sea, usually with hilly or mountainous sides, its upper end terminating at the mouth of a glen or valley. The word is Norwegian, and it is in Norway that fjords are most characteristically developed. But our own word "firth" is the same, and along the western coasts of the British Isles are many excellent examples of fjords. With us they are usually termed lochs, as Loch Hourn, Loch Nevis, Loch Fyne, Gareloch, Lough Foyle; also, in Ireland, bays, as Dingle Bay, Bantry Bay.*

From what we know of the mode of operation of the various forces of denudation, there can be little doubt that fjords have been originally land valleys. The long inlet filled with salt water was primarily excavated as a glen upon the land, and the glen, by which the hollow of the fjord is prolonged inland into the interior, corresponds, in form and character, with that hollow,—is in fact an integral part of it. That the glens have been excavated by subaërial agents is a conclusion which will be stated and enforced in a subsequent chapter. Hence, if we admit the subaërial origin of the glen, we must also allow a similar origin to the seaward prolongation of the glen, that is to the fjord. Every fjord will thus come to be regarded as a submerged land valley. This is confirmed by the fact, that just as we do not commonly meet with but one glen in a wide mountain district, so we seldom meet with a solitary fjord. Like the glens, the fjords occur in groups, and when we see a long coast-line like that of the west of Norway or the west of Scotland pierced by innumerable fjords, we infer that the land has sunk down on that side so as to allow the sea to run far up and fill the submerged glens.†

4. Evidence from Coral-Reefs.—That wide areas of the sea-bed are undergoing a movement of subsidence was first made known from the growth of coral-reefs, as observed and explained by Mr. Darwin. He showed that the species of coral which produce great reefs only live in shallow water, where the heat and light are both vivid, and where the motion and play of the waves are rapid and continuous. A depth of about fifteen fathoms seems to be the downward limit at which these animals can flourish. Great wall-sided Atolls and Barriers, then, rising from depths of 2000 feet or more, must have commenced their growth in shallow water, and continued it upwards, at such a rate as to have always kept their living surface near to the surface of the ocean, while the rock base, on which they rested, gradually subsided beneath it. Hence, as coral-islands are found rising from very deep water far from any land, Mr.

* There is a habit of writing this word "frith," instead of "firth." *Frith* may be the Latin word *fretum*, a strait or passage between two seas; but *firth* is the old Norse word *fjord*, a sea-loch.

† See Geikie's *Scenery of Scotland, viewed in connection with its Physical Geography*, p. 125; Ramsay, *Quart. Journ. Geol. Soc.*, vol. xviii. p. 125.

Darwin drew the conclusion that, when the corals began to build, there was land where there is now sea, and that, since that time, a wide-spread subsidence of land and sea-bed must have taken place. The following resumé of his argument may be of interest to the student.*

Fringing-reefs are banks of coral which grow along the margin of the shore. The distance of the outer margin of a fringing-reef from the shore depends on the slope of the sea-floor between the beach and the fifteen-fathom line. This is shown in Fig. 128, where the horizontal line S S represents the surface of the sea, and

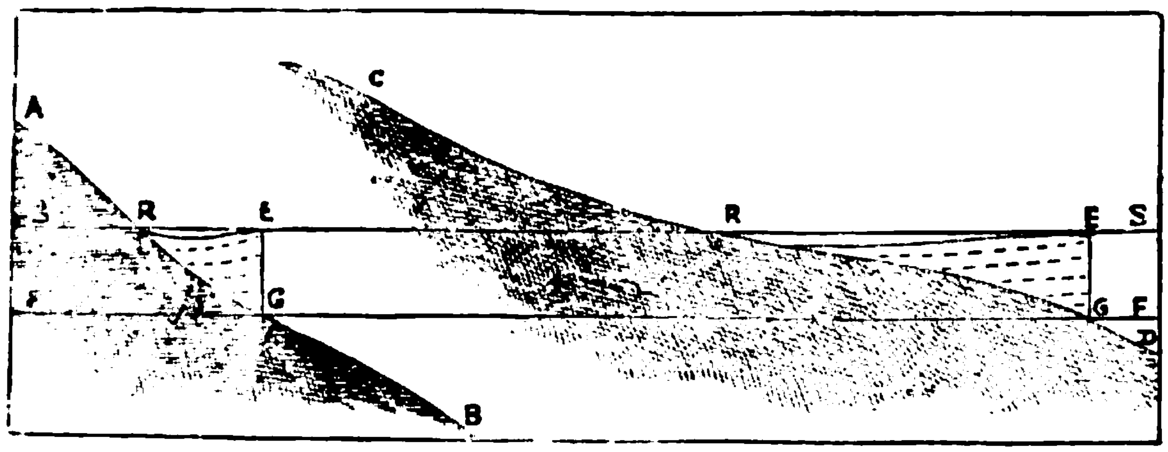

Fig. 128.

F F a depth of fifteen fathoms below it. A B and C D are supposed to be two shores, sloping at different angles, which become coated with corals down to the fifteen-fathom line, those corals eventually accumulating up to the surface, so as to form the fringing-reefs R E G. The bulkiest corals grow farthest from land, so that, while they commonly reach the actual surface of the sea at the outer edge of the reef, there is often a lagoon of deeper water left between the outer edge and the shore. The width of the reef R E is of course greatest where the slope of the rocks forming the sea-bottom was originally least, and the outer edge of the fringing reef, when laid down on a chart, becomes like a line of soundings upon it, to show where the depth of fifteen fathoms originally commenced, and immediately outside of which it is still to be found.

Now, suppose the whole country, of which A B and C D are the shores, to sink slowly down, vertically, into the sea, the whole sea-bottom around that land of course partaking of the movement. The sea will flow farther in upon the sloping land ; as the latter sinks, the width of the reefs R E will be increased, and if the rate of depression has been such as still to allow of the growth of the coral, especially about the outer edge E, the reef will shortly reach again the surface of the sea, and the height of the outer wall G E will become greater than fifteen fathoms. Let this sinking of the earth's surface go on slowly and gradually, or by little starts of a few inches or a few feet at a time, with the requisite intervals between them, and the width from the outer edge of the reefs E to the shore R may become indefinitely great, as well as the height of the outer wall G E. The depth of the lagoon also, between R and E, may in many cases be considerable from the absence there of coral-growth, and of debris derived from its destruction.

What was originally a Fringing Reef comes thus to assume the form of what is called a Barrier Reef. The outer edge of a barrier reef runs generally parallel to the shores of the land inside it, but rises sometimes like a great wall from an outside depth of 1000 or 2000 feet, and includes a lagoon or channel between it and the land, many miles wide perhaps, of very great depth, and more or less encumbered with inner reefs, which have formed in favourable localities.

Should the land be an island, the shores of which do not extend beyond the

* Written by Mr. Jukes; the figures are from his *School Manual of Geology*.

warm seas in which alone the coral-reef-making animals can live, and that island be entirely surrounded by a barrier reef, it is obvious that if the depression proceed, the last peak of the island must ultimately sink beneath the waves, and the barrier that surrounded it, still continuing its upward growth, becomes an Atoll, or ring of coral reef, enclosing a lagoon without any island. No other dry land will then be left except the sandbanks formed upon the reefs themselves, by the piling action of the winds and waves heaping up the debris they have worn from the reefs.

Fig. 129.
Conversion of a Fringing Reef into a Barrier Reef, and then into an Atoll.

In Fig. 129 an attempt is made to represent this mode of operation, in which, as it is impossible to introduce a motion of the parts of the figure, different lines S S are drawn, to represent the unaltering surface of the sea at different times. Let the obliquely-shaded part in the centre represent the section of an island when the sea-level was at the lowest line S S, and the dark horizontally-shaded patch marked F F on each side of it represent a fringing reef which was then formed. Then let depression, as above described, commence and go on until the surface of the sea, with respect to the island, can be represented at different times by the higher lines S S. The old fringing reef will at these times have become a barrier reef, as indicated by the letters B B surrounding the slowly diminishing island; and, finally, the last peak of that island will disappear, and the surface of the sea, being represented by the highest line S S, the figure now becomes the section of an Atoll A A. An Atoll, then, is the tomb and monument of a sunken island, the approximate amount of depression being measured by the depth of the water outside its outer slope, where the fringing reef from which it sprang still exists beneath its base, and would, if it could be traced, mark the original shores of the old land.

Mr. Darwin * shows a vast area of depression to extend in the Pacific, from Pitcairn's Island and the Low Archipelago to the Caroline and Pellew Islands—a distance of more than 7000 statute miles. Between India and Madagascar is another such area more than 1500 miles in length.

The great barrier reef on the N. E. coast of Australia is 1200 miles long, and, including New Caledonia and the Louisiade, and the many intermediate reefs of what Flinders called the Coral Sea, that area of depression seems to be at least as broad. It is remarkable, as observed by Mr. Darwin, that between this latter area and that of the Great Pacific, there seems to extend a band or bands, where elevation rather than depression is taking place. Volcanoes and volcanic islands are numerous in these bands, spreading from New Zealand to the New Hebrides and New Guinea, and running thence through the Eastern Archipelago to Java and Sumatra. I can answer for raised coral-reefs—probably raised fringing reefs—existing in the country at Timor and Java, and some of the intermediate islands, at heights of one or two hundred feet at least above the level of the sea.

* The student is referred to Mr. Darwin's book on Coral Reefs, published in 1842, as one of the results of his voyages in the Beagle, for full descriptions of these coral reefs, and the first exposition of this doctrine of the depression of the ocean-bed as an explication of their phenomena. See also Dana, *Exploring Expedition Reports*, 1846, and 1849.

Summary.—From what has now been stated, it appears that widely-extended movements have been and are now going on within the crust of the earth, and that these movements manifest themselves at the surface, sometimes in the elevation, sometimes in the depression, of the land or of the sea-bed. When land rises or falls the change affects the climate of the regions so moved, and changes of climate react upon the various tribes of plants and animals of the land. In like manner, elevation or depression of the sea-bed influences the course of marine currents and the distribution of temperature in the ocean—changes which, as on land, tell upon the marine climates, and consequently upon the distribution of the plants and animals of the sea.

A consideration of the present denudation of the globe, as will be shown in a subsequent chapter, makes known to us that so universal is the waste of all land-surfaces, that, were there no compensating force at work, all dry land would eventually be worn away, and its debris would be deposited on the floor of the ocean. This compensating force is supplied by the subterranean movements which result in the permanent elevation of land.

But if we reflect a little on the necessary effects of such movements as those which we have been considering in this chapter, we perceive that, while the surface of the globe is affected, there must also be considerable changes brought about within the crust of the earth below the elevated or depressed areas. One result, which must often happen, is the enormous compression of the rocks at great depths. If it be true, and we cannot doubt that it is, that there has been a secular cooling of the whole body of the earth, and if the rocks composing the mass of the earth have on the whole contracted on cooling, the hardened crust must gradually have shrunk. In the course of this process both elevation and depression, on the largest scale, probably occurred, and at the same time enormous plication and crumpling of the rocks. There is good reason to believe that the elevation of mountain chains may very generally be due to the results of this slow secular refrigeration. It may seem paradoxical to speak of lofty mountain chains being due to a shrinking, instead of an expansion, of the earth's crust. But we must remember that while the general result was a diminution of bulk, the enormous strain of the shrinking crust would often relieve itself by the rise of long and variously-shaped portions of the outer shell. The form, direction, and size of these ridges would be determined by variations in the structure of the crust, by the position of the internal tunnels or reservoirs already referred to, and no doubt by many other local features, regarding which we know as yet little, and may never know much. This subject will be again referred to in the account to be given of the origin of mountain chains.

CHAPTER XVIII.

EARTHQUAKES.

Besides the slow movements, described in the foregoing chapter, there are others of a sudden and violent kind, which, though they do not produce the same extent of permanent change, yet give rise to far more disastrous temporary disturbance. These more rapid and sensible movements come under the general denomination of earthquakes. Their intensity varies, however, very widely. In many cases, as for instance in Britain, all that is usually felt is a mere vague underground rumbling, like the sound of distant thunder, or of booming artillery, or of a heavily-laden waggon drawn along a causeway. A little greater force of shock suffices to shake windows, pictures, glasses, and other loose objects; a heavier shock loosens chimneys, slates, plaster, or cracks walls, or twists round the upper parts of spires and monuments. From such comparatively slight manifestations we can follow the increase of intensity, until we meet the true and typical earthquake, when the ground, heaving up and down like the sea in a storm, is rent open, houses, churches, even entire cities, are reduced to ruins, cliffs are shattered, rivers and lakes ponded back, and the sea driven in great waves upon the land.

Definition and Laws of Earthquake motion.—Mr. Mallet* defines an earthquake as "a wave or waves of elastic compression, in any direction, from verticality upwards to horizontality, in any azimuth" (or compass bearing), "through the crust and surface of the earth, from any centre of impulse, or more than one, and which may be attended with sound-waves and sea-waves, depending on the impulse, and upon circumstances of position as to sea and land." He gives the following as the conclusions to which his careful researches had led him.

1. The "earth-wave of shock" appears to be the result of a sudden impulse or blow, such as a sudden volcanic outburst, sudden cracking of a mass of rock in a state of tension, sudden generation of steam from water in a spheroidal state, or sudden condensation of steam under pressure of sea-water. Such a sudden impulse would always cause a *wave*, that is a *rise and fall*, either in solid, liquid, or gaseous substances.

* In his Report to the Royal Society on the Neapolitan earthquakes of 1857, published in 1862 as a separate work, in 2 vols., by Chapman and Hall.

2. This wave is transmitted with great velocity, and affects any given spot for but a brief moment of time.

3. The waves travel in spheroidal shells, so that, as each reaches the surface, it spreads in circles larger and larger as it recedes from the point directly over the shock. Inasmuch, however, as the central impulse does not proceed from a mere point, but from a space often of large dimensions, the form of the waves will vary indefinitely from circles, and form closed curves of irregular shapes. This irregularity will be increased by their passing through heterogeneous rocks, which vary in density, hardness, number of joints, direction of dip, and other circumstances. The motion will be still farther complicated by return waves from the surface of rocks suddenly varying in density, etc.

4. The "angle of emergence" of the wave directly over the central impulse will be perpendicular to the surface, in a line or plane which he calls the "seismic vertical;" but this "angle of emergence" will decrease in proportion as we recede from this seismic vertical, so that, if we can determine that angle in two or three places, we can calculate the depth and extent of the "central impulse." This may be done by observing its effects of fracture, overthrow, or projection, on such things as substantial buildings. The intensity of motion will, of course, be greatest over the "seismic vertical," but it there exerts no overturning power. As we recede from the seismic vertical, the overturning power increases as the angle of emergence lessens. The intensity of the power diminishes in the same proportion, but there must be some curved line on the surface of the area affected, when the overturning power is at a maximum, in consequence of the wave emerging with sufficient obliquity, before it has lost the requisite intensity.

5. The velocity of transit of the wave must not be confounded with the "velocity of shock," or that of motion in any particle affected by it. Half the amount of actual motion of any particle above and below its original place he calls the "amplitude" of the wave. The form of the wave travels half as fast as a cannon-shot, but the motion of a particle in amplitude is not more rapid than that of a body falling from a height of three feet. It is, however, the latter motion which does the mischief to buildings.

In the Calabrian earthquakes, in 1857, Mallet found the velocity of transit of the wave to have varied, according to the rock formations it traversed, from 658 feet to 989 feet per second, with a mean of 789 feet per second. The velocity of shock, however, came out only 12 or 13 feet per second, and the "amplitude" of the wave not more than 3 or 4 inches. From observations on the effects upon buildings, enabling him to calculate the angle of emergence of the wave at different places, Mallet fixed the position of the Calabrian centre of impulse

and calculated that its mean depth was 5·3 miles, but that it was 9 miles long horizontally, and 3 miles vertically.

From the description given by Humboldt of the earthquake at Riobamba, in which the bodies of people were projected a height of 100 feet across the Lican torrent on to the hill of La Culla, Mallet calculates that the velocity of shock there must have equalled 80 feet per second, or more than five times that of the Calabrian earthquake of 1857, and that the depth of the central impulse must have been 30·64 geographical miles, which he supposes to be, perhaps, the greatest possible depth. This would be represented by one-eighth of the space between the outer and inner circle in Fig. 126, page 319.

Effects of Earthquakes.—For descriptions of recorded earthquakes the student will consult such works as those mentioned in the note below.* He may find it of service, however, to have the effects produced by earthquakes summarised in the following paragraphs:—

1. Heaving or Undulatory Movement of the Ground.—If we watch the vessels in a harbour, when a strong swell is coming in from the sea outside, we see the masts rocking uneasily backwards and forwards, as each undulation passes under them. The motion produced by an earthquake wave is of the same kind. Trees are bent over, now to the one side and now to the other; sometimes their upper branches touch the ground. In a wooded country, the crashing of boughs is heard far and wide as the trees are thrown against each other; after the calamity has passed the ground is found strewed with broken branches and prostrated trunks. Among the still erect trees, some are found locked into each other—the boughs of one having been inextricably twisted into those of its neighbour, as they were swung to and fro by the rocking ground. Tall pinnacles of rock, in like manner, after reeling backwards and forwards, sometimes fall in headlong ruin into the valley below, hurling down woods and hamlets, and spreading desolation over cultivated fields.

It is natural, however, that these effects should be more noticeable among human works than in nature. Accordingly, it is the results of earthquake shocks on buildings which have been chiefly chronicled, and which have enabled us to arrive at some knowledge of the nature of the movements by which these shocks are produced. When a shock of full violence passes under an inhabited country, the houses and other buildings rock to and fro like the ship-masts in the harbour. The result is, that in a few seconds the walls give way, and the buildings sink in ruins to the ground, burying such of the luckless inmates as have been unable to escape. Sometimes it is the buildings solidly constructed of stone which suffer most, and lamentable instances are on record of thousands of people having been crushed under the ruins of churches, into which they had gone either for the purposes of devotion or for greater security. At other times the well-built houses escape, whilst those more slimly formed, of wood or of brick, tumble down as if they had been built of cards. In such cases the different modes in which the houses suffer appear to depend upon the nature of the ground on which they are built, as well as of the materials of their construction. There seems something

* See Von Hoff's *Veränderungen der Erdoberfläche*, parts 2, 4, and 5; Mallet's work, already cited, and his *Earthquake Catalogue*, published by the British Association; Lyell's *Principles of Geology*, vol. ii.; Somerville's *Physical Geography*. An interesting resumé of the earthquakes in 1867-8 was given by C. L. Griesbach to the Geographical Society of Vienna, and is published separately under the title *Erdbeben in den Jahren* 1867 *und* 1868.

almost capricious in the earthquake shock. A whole street will sometimes be levelled to the ground, except one house, which may be but little injured; half of a house will be thrown down, while the other half remains not much the worse; a pillar or obelisk will have its stones twisted round upon each other, and yet the whole remain still standing. Instances are also recorded of buildings having been cracked in two, the one half sinking down several feet below the level of the other.

Besides the undulatory movement of the earthquake, which causes perpendicular objects to sway to and fro, there is in the centre of the disturbed area (that is, more or less directly over the focus of disturbance) an upward jerking motion, which affects even horizontal bodies. For instance, cases are known where the paving-stones of a street have been pitched out of their sockets, and have been found, after the earthquake, lying with their under surfaces uppermost. This motion, combined with the wave-like one, produces sad havoc in a town. On sloping surfaces stupendous results are often brought about. Thus, along river-courses, banks of loose earth, sand, or gravel, are shattered, and masses are launched down towards the river. On mountain slopes also, large areas of soil and debris have been shaken loose from the rock on which they rested, and hurled into the valleys. Similar results take place along the margin of the sea. Earth, soil, and stones are thrown from steep slopes to the beach; and cattle browsing on these declivities are likewise swept down; even solid cliffs are shaken, and large fragments of them detached to fall into the waves below.

2. Rending open of the Ground.—Besides the effects produced by the undulatory or jerking motion of the earthquake on objects at the surface, another highly important feature is the actual rending open of the ground. This does not necessarily take place in all earthquakes; but it is one of their frequent and terrible accompaniments. Cracks of the soil are formed, and these vary in size from only a foot or two in length, and an inch or two in breadth, up to rents ninety miles long, and sometimes several yards in diameter. During the progress of an earthquake such cracks are observed to open and close again sometimes in rapid succession. Trees, houses, men, cattle, anything, in short, which may happen to be on the surface at the time, fall into the chasm opening beneath them, and may be there engulfed for ever. Yet cases are known where men have fallen into the cracks, and though the walls have closed upon them, they have been thrown out again alive when the chasm reopened. Quantities of mud and sand, along with water, are sometimes ejected from the rents, or from curious funnel-shaped cavities formed in the ground at the time. The fissures either close again permanently, and, after the earthquake, cease to be visible, or they remain open, and may continue so for many years, until, as their sides crumble down, they become filled up, and in the end gradually obliterated, or in some cases they may give rise to new minor valleys.

3. Effects on the Ocean.—It is evident that no shaking of the solid land could take place without affecting more or less the waters of the ocean. This would be the case if the seat of the earthquake shock, or the place where it first reached the surface from below, lay beneath the inland parts of a country, and the earthquake wave undulated outwards to the sea-margin. But it often happens that the point of origin of an earthquake lies somewhere beneath the bed of the ocean, and though the actual earthquake wave may never be propagated through the solid crust to reach the land, the commotion it produces in the waters gives rise to an ocean-wave which rolls landward until it breaks upon the coast. In truth, in all maritime districts subject to earthquakes, the amount of disaster achieved by the shaking of the ground is often far less than that which is worked by the inroad of the sea. The inhabitants have, perhaps, been terrified by the first shock of the earthquake, when, before they have recovered from their surprise, they see the sea in front of them retire for several hundred yards, laying bare the bottom of the harbour or the beach. By-and-by, when it has reached its farthest limit of

retreat, they watch it surge and foam, and, gathering itself into a broad breast of water, rush furiously towards the shore. In a few minutes hundreds or thousands of the inhabitants are drowned, or dashed against houses, or transfixed with broken wreck. What of their city has been left unprostrated by the earthquake is now inundated, and in great part levelled by the torrent of sea-water. Ships riding in the roadstead, even heavily-armed men-of-war, are swept inland, and left high and dry, half-a-mile, it may be, from the shore. In short, wherever the sea-wave reaches, it carries with it indescribable desolation. Property of every kind is destroyed, and in a few moments a busy seaport-town is actually blotted out of existence.

4. Permanent Changes of the Surface.—The effects, which we have hitherto been considering, although of terrible import in relation to man and his works, are not those features of earthquake phenomena which leave the most permanent marks on the surface of the earth. A city may be shaken to pieces or destroyed by the ocean-wave, but its site may become again covered with a new town, and every memorial of the catastrophe be effaced. The present city of Lisbon is built on the ruins of that which was destroyed by the great earthquake of 1755; and in digging the foundations of new houses and streets, the remains of the destroyed city are continually met with. A forest may be shattered, but time will eventually replace the prostrated trees. Masses of earth or blocks of rock may be loosened and fall into the valleys below, but the scars which they leave will ere long be healed. But there are accompaniments of earthquakes which more permanently alter the surface of a country, and which show that earthquakes play an important part among the agencies by which the external contour of our globe is modified.

By the shifting of large masses of rock or debris in the manner above described, the drainage of a country may be considerably altered. When these loosened materials fall across the course of a river, one of two results follows—either the river is deflected from its old course, and compelled to form a new channel, or its waters are ponded back, and a lake is formed. In the former case, over and above the destruction of cultivated ground which may have been caused by the landslip, the river, in cutting out its new course, may have to traverse fields and gardens, which are of course destroyed by it. When its course has been thus fairly altered, the river is likely to retain for a long time the channel into which it has been driven, and hence the drainage of the valley is considerably modified. In like manner, the formation of a new lake may entail the loss of much valuable soil. Moreover, as the barrier by which the waters of the lake are dammed back may be of loose incoherent material, there is the risk that, during some season of unusual rains, it may give way, when the contents of the lake will of course rush down the valley, carrying ruin to wherever they reach.

During the concussion of the ground, it sometimes happens that the barrier of an old lake is lowered or cracked in such a manner as to allow of the escape of the waters. After the earthquake is over, the lake is found to have disappeared. Rivers, too, have been known to be engulfed, pouring into rents of the ground, to reappear again perhaps at the surface some way down the valley. Although the amount of change effected by any single earthquake upon the drainage of a country may not be very great, we must nevertheless bear in mind that if even slight changes are produced year after year, or century after century, the sum total of their results may come in the end to be not inconsiderable. Whatever interferes with the flow of water across a country necessarily exercises an important influence upon the outline which the surface of that country will eventually assume; for, as will be pointed out in a subsequent chapter, it is mainly by the power of running water that the valley systems are carved out, widened, and deepened.

5. Permanent Alterations of Level of the Land.—But of all the results which are brought about during the passage of an earthquake, there is none which

so appeals to our imagination, as evincing the mighty energy of the underground forces, or which is in itself really of such importance in the history of a land-surface, as the permanent change of level of the region affected by the earthquake Sometimes the movement is an upward one, and the ground remains at the height to which it has been raised; sometimes it is in a downward direction, and the land is left permanently at a lower level than it had before. In either case, the effects may be traced over wide areas, hundreds or thousands of square miles of country having been upheaved or depressed to a distance of several feet above or below their former level. The reality and extent of this change of level are best seen along the sea-margin. When the land has been elevated, it seems as if the sea had retired from its ancient limit. The beach and all the rocks which used to be washed by the tides are laid bare. Shell-fish are found still adhering to the places where they used to live, though now far removed above the reach of the waves; large quantities of fish, killed by the shock or cast ashore by the irruption of the sea, are strewn along the beach, and the air soon becomes foul with the smell of the decayed animal matter. In the end, the upraised beach comes to be covered with vegetation; it may be that even villages and towns are built upon it; and as it becomes absorbed into the general body of the land, the traces of its former occupation by the sea gradually fade away. In this manner a new selvage of land is added to the coast-line. If, on the other hand, the earthquake has been accompanied by a subsidence of the ground to a lower level than it formerly had, this will be marked along the maritime districts by an encroachment of the sea. The waves are then found breaking over ploughed fields; trees, roads, houses are submerged; villages and towns are inundated, and their inhabitants compelled to build anew within the narrowed limits of the land.*

Distribution of Earthquakes.—Although earthquakes occur in regions far removed from any volcanoes, they are yet most abundant in volcanic districts, where they precede or accompany volcanic eruptions in such a way as to indicate that between the two forms of subterranean commotion there is a close connection. If the student will consult a good map of the distribution of earthquakes and volcanoes over the globe (such as that in Keith Johnston's *Physical Atlas*, Plate x.), he will see this connection brought out very clearly. From the Azores eastwards along the Mediterranean and far into Central Asia, he will perceive that there stretches a broad band of the earth's surface, partly land and partly large inland seas, subject to frequent shocks of earthquake. In this band he will notice that there occurs a long broken line of volcanic foci. From the volcanoes of the Azores and Canary Islands we pass on to Vesuvius and Etna, then by those of the Greek Islands, and the extinct craters of Syria, to the yet active volcanoes of the Caspian and the Thian Shan mountains. In like manner the whole of the western sea-board of the American continent is subject to earthquakes, sometimes of great severity, and, on looking at the map, we observe that this region is thickly set with volcanoes along the great mountain-chain from Patagonia northwards into Mexico.

* The above summary of the effects of earthquakes is taken, with some slight alterations and additions, from a paper on Earthquakes and Volcanoes, written by the present Editor for Chambers's *Miscellany of Tracts*, 1870, to which the student may be referred for further general information on the subject.

Extent of Ground affected by an Earthquake.—The area over which the shock of a single earthquake may be felt varies indefinitely. With such feeble earthquakes as those of which a number occur every year in the British Islands, the tremor does not extend beyond the limits of one or two counties. But when the shock is one of full intensity, it may be felt over a space of many thousand square miles. During the great Lisbon earthquake of 1755, for instance, the effects of the earth-wave were felt over nearly the whole of Europe; from Iceland to the north of Africa houses trembled, lakes, canals, and ponds were agitated. The sea rose in a great wave round the coasts of Britain, and the same wave rolled westwards and broke in great fury over the islands of the Antilles. Even the waters of Lake Ontario were disturbed. In August 1868, an earthquake threw down the towns and cities of Peru and Ecuador over a strip of country two thousand miles long, extending from the coast-line up into the chain of the Andes.*

* The student who would pursue this subject will find the work of Von Hoff and those of Mr. Mallet already cited his most useful authorities. He should also study a map of the distribution of earthquakes, such as that in *Johnston's Physical Atlas*, or in Mr. Scrope's work on *Volcanoes*.

CHAPTER XIX.

VOLCANOES AND VOLCANIC ACTION.

Structure of a Volcano.*—A volcano is a more or less conical hill or mountain, composed entirely, or nearly so, of materials which have been ejected from beneath the surface through one or more pipes or shafts communicating with a highly-heated portion of the earth's crust. It has a truncated summit, on which lies a basin-shaped cavity, known as the *crater*, at the bottom of which is the mouth or opening of the orifice up which the subterranean materials are erupted. These materials consist—1st, of aëriform discharges, as gas and vapours, particularly steam; 2d, of dust, stones, and large blocks of rock; 3d, of molten rock or lava. An *active* volcano is one from which some one or other of these three forms of discharge is always being given off. An *extinct* volcano is one from which the discharges have ceased. In a volcano which is known to be active, however, the discharge may sometimes be very feeble, consisting perhaps merely of an occasional emission of steam, while from a volcano which has been extinct during the whole of human history, quantities of carbonic acid gas or heated water may still be given off.

The conical form of a volcano arises from the piling up of the solid materials round the orifice from which they are discharged. The loose dust or "ashes," and "lapilli" or stones, on their ejection into the air, fall partly back into the shaft, but chiefly round its margin. Hence, as the eruptions continue, the hill grows in height and diameter. Streams of "lava" or molten rock flow from the lips of the crater, over the sides of the cone, or escape through some weaker part of the sides or base of the hill, and descend in streams or "coulées" into the valleys or level country below. Hence a section of a typical volcanic cone would show a central pipe or shaft, from which numerous irregular lenticular beds of "tuff" (that is, solidified "ash") and lava dip away outwards, their

* For full details on the subject of this chapter the student will do well to consult the instructive work of Mr. Scrope on *Volcanoes* (second edit., 1862), and Dr. Daubeny's work on the same subject. The former takes up chiefly the geological aspect of volcanic action; the latter deals largely with the chemical aspect. Much information may also be obtained from Mr. Darwin's *Volcanic Islands* and *South America*, the papers and works of Sir C. Lyell, Waltershausen's work on Etna, and from the works of such travellers as Humboldt, Von Buch, Dana, and many others.

inclination next the crater being as high as 30°, and lessening towards the lower ground, till it passes into horizontality. There is also an inclination inwards round the walls of the crater, owing to the loose materials rolling back again down the inner slope of the crater (see Fig. 130).*

When the original conical pile acquires any size, lateral orifices or craters are formed about its flanks, and produce little secondary cones, which often, as in Etna, stud all the sides of the main mountain with minor hills; many of these doubtless become buried as the process goes on, either under beds of tuff or streams of lava, so that, if we could take such a cone to pieces, and demonstrate each step in its formation, it would be found to have been a very long and complicated process. Sometimes a row of cones is formed along a certain line of country, without any central dominant one; sometimes two or more neighbouring cones grow to nearly equal size, and sometimes one of these is buried under the accumulations of the other, which either temporarily or permanently assumes the superiority.

Fig. 130.
Ideal section through volcanoes.

Fig. 130 may be taken as a rough diagrammatic idea of the mode of formation of volcanic cones and craters, the parts crossed by vertical lines representing the lava-flows, and the other lines the accumulation of beds of ash, including under that term all other ejected matters. In reality, the structure will almost always be much more complicated, the minor cones and lateral vents being greatly more numerous, and the whole traversed in all directions by ramifying dykes and veins of lava, with lateral pipes for some of the lateral cones branching from the main vertical funnels.

Volcanic Products.—These have been just referred to as of three kinds—gaseous, solid, and liquid.

1. Gases and Steam.—Carbonic acid gas, sulphuretted hydrogen,

* It is not necessary to do more than allude in a footnote to the theory of Humboldt, Von Buch, and others, that a volcanic cone is due mainly to an elevation of the ground beneath the focus of eruption, and not to the gradual accretion of material round the point of emission. The student will find this theory amply disproved by Mr. Scrope (*Volcanos*, 2d edit.; *Volcanoes of Central France*; and papers in *Quart. Journ. Geol. Soc.*, xii. 326, and xv. 505); and by Sir Charles Lyell (*Phil. Trans.*, clxviii. part 2, and *Principles of Geology*, vol. i.

nitrogen, hydrogen, and hydrochloric acid gas, have been found to rise from active volcanoes.* But the most frequent and abundant of the aëriform discharges are those of steam. In all eruptions, whether of ashes or of lava, steam rises in enormous quantities, and being condensed into clouds, falls to the earth as rain. It is likewise given off from lava-currents to such an extent that Mr. Scrope has even maintained that fluid lava owes its mobility to the presence of water, or the vapour of water, in the minute interstices between the crystals.

2. Ashes and Stones.—The explosions of an active volcano are powerful enough to burst open any lava which may have partially solidified in the vent, to eject its fragments to a great height in the air, and, by constant ejection and trituration of the broken materials, to produce an enormous amount of fine dust or "ash." This fragmentary material necessarily varies greatly in composition and texture (see Chap. V. p. 105). Where the lava in the pipe beneath has been trachyte, the ash gives rise to a trachyte-tuff; where it has been pyroxenic, a pyroxenic-tuff or peperino is produced. Sometimes the tuff is made up of the finest, almost impalpable powder, and from this texture there is every gradation, up to a coarse breccia or agglomerate. When the fine volcanic dust is ejected to a great height, it occasionally comes into the track of an upper current of air, and may be borne to distances of 800 miles before falling to the earth. Thus, showers of ash now and then descend pretty thickly upon parts of the Shetland and Orkney Islands during an eruption of one of the Icelandic volcanoes. When the loose ejections of a volcano fall on the sides of the cone, they assume a stratified arrangement, in irregular lenticular beds, dipping away from the crater. This is the case even when they fall loosely, but when, as often happens, the plentiful discharge of steam gives rise to torrents of rain, the loose ash becomes mingled with the water, and forms a kind of volcanic mud, which may be as destructive to vineyards and houses as molten lava.

3. Lava.—Under this term may be included all the products of a volcano which are ejected in a molten state. The mineralogical distinctions of these rocks have already been given (p. 100 *et seq.*) A current of lava, or coulée, may issue either from the lowest part of the edge of the crater, or from some lateral orifice of the volcano. It may vary in size from a mere rill, which does not reach the base of the central cone, like the obsidian coulée on the north side of the Island of Volcano, to a vast flood of molten rock, spreading, as in the case of the Skaptár Jokul in 1783, 45 miles in one direction, and 50 miles in another, with a breadth of from 7 to 15 miles, and a height of from 100 to as much as 600 feet.

The upper surface of a lava stream, cooled in the open air, is usually

* See Daubeny, *Op. cit.*, and Bischof's *Chemical Geology*.

a mass of loose slags and cinders, like the "clinkers" of an iron-foundry. Where the stream first issues from the earth, it seems perfectly fluid, and glows with an intense white light and heat. It then moves somewhat rapidly. But a few yards further down it begins to darken, and assume a rough slaggy crust, under which the red-hot lava continues to move onwards. Its further extremity is a slowly-moving mass of loose porous blocks, rolling over each other with a harsh sound, like the grating rattle of iron slags.

All rock is a bad conductor of heat, so that, when once a lava stream acquires a cooled crust, the mass within may remain glowing hot for a considerable time. It is possible to walk about on the cooled surface of a lava stream, and yet to roast eggs or light cigars in the crevices of the crust. A lava stream may retain, even for ten years or more, sufficient heat to give off steam, and to make it impossible to hold the hand in some of the crevices. Caverns are sometimes formed in lava streams by the sudden escape of the molten mass below, leaving the cooled crust standing like the roof of a tunnel. In a mass, therefore, which cooled thus slowly in the interior and rapidly outside, the upper surface may be light, porous, and cindery, the lower surface somewhat similar, and the central portion solid, compact, or crystalline. As a matter of fact, wherever old lava streams have been cut into, either naturally or artificially, we find the vesicular character of the upper surface gradually but rapidly disappearing below, and the rock passing into a hard, compact stone, often columnar, and frequently quite crystalline.

Fig. 181.
Section of a lava coulée resting on tuff. Shore at Torre dell Annunziata, Naples.

a. Slaggy upper surface, 2 to 3 feet thick; b. compact central portion, a grey carious lava, with augite and olivine, from 6 to 15 or 20 feet thick; c. slaggy lower surface, 1 to 3 feet; d. layer of red earth—an old soil; e. ancient tuff.

In describing the structure of a sheet of contemporaneous trap, we pointed out the fact that its upper and lower surface are very com-

monly scoriform, and that, in this respect, it closely resembled a modern lava (see p. 273). In illustration of this resemblance, or rather, indeed, identity of structure, the foregoing figure (Fig. 131) is given. It was sketched by the editor on the coast of the Bay of Naples, where one of the lavas of Vesuvius has come down to the sea. The lava is eight or ten to fifteen or twenty feet thick, and shows most admirably the scoriaceous upper and under surface (amounting in each case to a thickness of from one to three feet), and the central solid compact portion.

The amount of fluid lava ejected during some modern eruptions is very noteworthy. An excellent example was afforded during the well-known eruption of Skaptár Jokul already cited, in which floods of lava wholly obliterated some valleys, filling up gorges 600 feet deep and 200 feet wide, spreading over plains 15 miles wide with floods 100 feet deep, the terminations of some of the lava streams being 90 miles apart. Had this eruption taken place in the south of England, all the hills from the neighbourhood of London to that of Gloucester might have been capped by great plateaux of basalt, from 100 to 500 or 600 feet thick.*

Association of Siliceous and Basic Lavas.—In many volcanic regions there appears to be an alternation, or to have been a succession, in the different products; the lavas being at one time trachyte, and at another dolerite. It was formerly supposed that the trachyte was always the lower or the older of the two, and that flows of trachyte were never found above flows of basalt or dolerite. Lyell, however, has shown that some of the newest lavas in Madeira are trachytic, while they cover others consisting of doleritic compounds. Bunsen, in a paper formerly cited, in speaking of the trachytic and augitic lavas of Iceland, refers their origin to two separate volcanic foci, and even speaks of a third separate volcanic focus for the intermediate lavas, though he also speaks favourably in another place of all the volcanic rocks arising from one mass. Durocher, too, in his essay on Comparative Petrology, referred the two classes of igneous rocks of all kinds—namely, the siliceous and the basic—to the existence of two separate "magmas" below the crust of the earth, the siliceous or lighter floating over the basic or heavier, and ejection taking place from one or the other, according to the strength of the impelling force; the ejection of the lighter therefore generally preceding that of the heavier.

The identity or very great similarity of the various volcanic products in all parts of the world, seems to point to a common origin for them. The frequent association in all parts of the earth of the two great classes of these products, the trachytic and doleritic, seems to show that their difference is not so much due to diversity of origin, as

* See Lyell, *Principles of Geology*, vol. ii. p. 52.

to some cause tending to segregate the one from the other, out of a generally diffused mass. The association of felstones and greenstones among the traps seems to be reproduced in that of trachyte and dolerite among the lavas.

Dykes and Veins of Lava.—As the trap-rocks abound with dykes and veins which seem to be sometimes the mere extensions of the mass below into the crevices of the rocks above or around it, sometimes apparently the feeders of still higher overlying masses, so volcanoes are penetrated in every direction by dykes and veins of compact lava, serving often to bind together or to support the otherwise incoherent materials. We must be aware, although we cannot see it, that every lava stream had its central pipe or feeder in the interior of the mass from which it proceeds. It is probable that, both in the case of traps and lavas, the size of the feeders often bears but a small proportion to the mass of the overlying rocks that proceeded from them.

It is not absolutely necessary, in the case of lavas, any more than in that of traps, that the flow of lava and the central pipe or feeder should remain in connection; for, when the lava ceased to be impelled so as to flow over the crater, the portion left in the funnel would sink down, and perhaps ultimately consolidate at a considerable distance below, and possibly form there a rock considerably differing in texture from the erupted lava, or the connection might be severed by the successive explosions of the volcano, or by subsequent denudation.

Fig. 132.
Sketch of the cliffs near Calheta.

Numerous dykes traverse the sides of the great valley scooped out of one side of Etna, called the Val del Bove, and instances are figured by Waltershausen,* of veins of lava traversing beds of tuff, both verti-

* In his magnificent work on Etna.

cally and horizontally, the latter often splitting into bifurcations among the tuffs. Every volcanic district, which has been laid open by denudation, exhibits similar facts. The cliffs, for instance, along the south coast of Madeira, west of Funchal, expose numerous dykes traversing the beds of tuff exposed therein.* Fig. 132 exhibits in one cliff portions of beds of lava, some of them columnar, interstratified with tabular laminated beds, against the denuded edges of which pale cream-coloured beds have been deposited in an inclined position, as shown in the left-hand corner of the sketch, with two grey dykes cutting across these beds. In Fig. 133, several veins or dykes of a hard grey lava

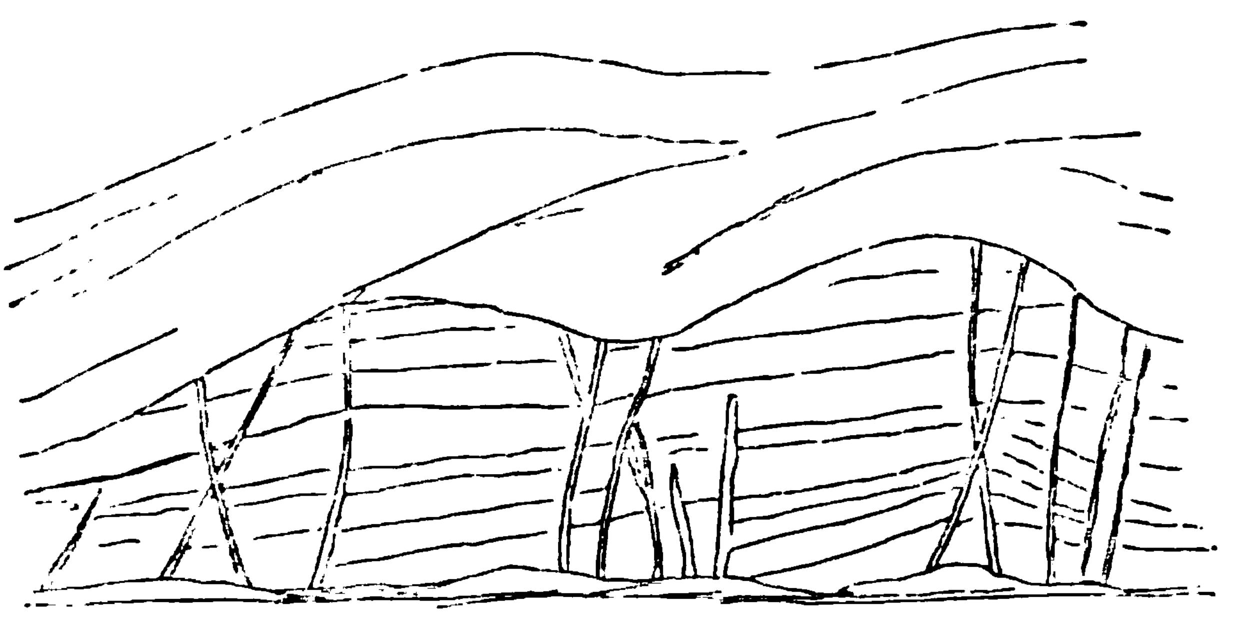

Fig. 133.
From a sketch a few miles west of Funchal Point.

cut through rudely stratified coarse tuff of a dull red colour, some of the dykes being also cut by similar ones of more recent date.

Examples of Volcanoes.†—The old volcanic islands of Madeira and St. Helena have had their cones obliterated by atmospheric erosion, and have been deeply cut into by the sea, so as to be girdled with lofty vertical cliffs along most of their sea-board.

Peak of Teneriffe.—When I paid a hasty visit to the summit of the Peak of Teneriffe with Captain Blackwood and some of the officers of H.M.S. "Fly," in May 1842, and after ascending the mountain to the height of about 9000 feet, rode across the plateau called the "Pumice Plains," towards the summit cone which rises from one corner of them, I was struck by the aspect of the circle of broken precipices surrounding the plateau. The ravines which cut through that surrounding wall show the outer slope of the rude beds composing it, and the note I find in my journal respecting them is the following:—"This plain is bounded in some places by an entire wall of rock, in others by broken and craggy hill, as if it had once been the interior of some enormous cone, of which these were only the ruined fragments." On subsequently reading Von Buch's account of the

* Figures 132 and 133 were sketched by Mr. Jukes from the deck of H.M.S. "Fly," when sailing close in along this coast, in April 1842.

† Written by Mr. Jukes, from his own observations among the volcanic islands of the Atlantic and Indian Oceans, and some of those of the Eastern Archipelago.

Canary Islands, I was greatly surprised to find that he supposed this circular wall, with its outward sloping beds, to have acquired its height and position from a central action of elevation subsequent to the deposition of the beds. So far as I had observed, there was no warrant for such a supposition. It was clear, indeed, that the whole island had been elevated since the volcanic action had commenced, because I had seen in the sides of a ravine near Santa Cruz, horizontally and regularly stratified beds of volcanic sand and pebbles, that seemed certainly to have been arranged under water;* but then these beds remained horizontal, proving the elevation to have been a general one, lifting the whole mass vertically, without tilting the beds in any direction.

Island of St. Paul.—We subsequently visited the little volcanic island of St. Paul's, in the centre of the South Indian Ocean, of which a chart, constructed by Staff-Commander Evans, was afterwards published by the Admiralty. This island is three or four miles across, with a flat-topped curved ridge, 820 feet high, nearly surrounding a circular crater, into which the sea now flows from one side, and which, at the sea-level, is almost half-a-mile in diameter. From the summit of the circular ridge the island slopes gently down towards the sea on all sides, except the east, where there are vertical cliffs formed by the sea having cut into the centre of the original island, so as to gain access to the crater. On the south side of the entrance, the wall bounding the crater was excessively thin, vertical on the outside, and sloping steeply on the inside, so that it must shortly be removed entirely, and all that side of the crater laid open to the sea. The entrance was not more than 100 yards wide, and only just deep enough for a boat, but inside there was a depth of 30 fathoms in the centre of the crater, with a bottom of black mud. This funnel-shaped pool was surrounded on all sides but one by the ring of high land before mentioned, the inside slope of which was precipitous near the top, but had a steep talus of rubbish clothed with coarse grass below. At several parts of its beach, hot smoking water trickled through the stones, having at one place a temperature of 138° F., and at another, one of 150° F., while the temperature of the water in the crater, both at the surface and at the bottom, was precisely that of the sea outside, namely 54° F. (This was on August 5th, 1842.) A bank of soundings stretched off the entrance to the crater, on the eastern side of the island, for a distance of nearly a mile, and a tall detached pinnacle of rock rose from this near the entrance to the crater. This bank was evidently the base from which the rocks that once surrounded the crater had been removed, by the sea cutting into them, all except the pinnacle above mentioned. The island seemed wholly composed of dark lava, interstratified with beds of sand, ashes, and blocks, varying from black to red and cream-coloured. They dipped but slightly outwards, and at one part seemed to dip inwards or towards the crater.

Another volcanic island, called Amsterdam, rises some sixty miles to the north of St. Paul's, these being the only spots of land in these latitudes between Africa and Australia.

Crater of the Bromo.—In November 1844 I had an opportunity of visiting the crater of the Bromo, in Java. This is in the centre of a rugged and rather narrow plateau, called the Teng'ir, rising in some parts to upwards of 8000 feet above the sea, and stretching in a curved line between the noble cones of the Semiru and Arjuno, so as to include the beautiful valley of Malang in a semicircular sweep. This mountain mass is all volcanic, its external parts consisting chiefly of fine-grained dust and ashes, enclosing, however, solid crystalline lava below. Its sides are furrowed in every direction by ravines with narrow ridges between them, the whole clothed with magnificent forests; tall pine-like casuarinas cresting the ridges up to a height of 6000 or 7000 feet.

* See Plate xii. in *Popular Physical Geology.*

On the central and most massive part of this plateau is a crater four or five miles wide, surrounded by a ring of precipices varying from 200 to 1200 feet high. In the centre of this great crater rises a cluster of minor cones, some of the craters of which are continually belching out smoke and steam, and sometimes ashes and hot stones. This cluster of cones forms a conical hill, rising in the centre of the old crater. The space between it and the foot of the surrounding precipitous wall is often more than a mile in width, and is covered with fine sand, and known by the name of the "Laut pasir" or sandy sea. The surrounding wall seemed quite unbroken, for we had to ride round the summit of one side of it by a narrow and giddy path, in order to take advantage of a sort of buttress-like ridge, apparently made of fallen fragments, to gain access to the interior, and on the other side the path at two places led by sharp ziz-zags up the side of the precipice. These paths seemed to be the only modes of communication between the villages on the outside of the mountains, some of which are places of great resort. Beds of hard trachytic, sometimes porphyritic, lava were visible in the face of the surrounding precipice, which, though they looked horizontal when viewed from the interior, probably dipped outside down the mountain. It seemed to me perfectly impossible that such a crater as the one I have here described could be formed by an action of central elevation. On the other hand, looking at the grand cone of Semiru, which rose a few miles to the south-west, it was obvious that it only required the upper 3000 feet of that lofty pile to be removed, —either blown into the air or undermined and engulphed in the central cavity of the mountain, for an exact repetition of the Bromo to be produced.

One thing struck me particularly in this central conical group of confluent cones, which was, that the one in action was perfectly smooth and regular outside, like a loaf of sugar, while those that had shortly ceased to eject materials showed the irresistible progress of denudation in the commencement of rain-gullies radiating down their slopes. Those that were still older, as proved by young trees having commenced to grow on their flanks, had these gullies much deeper and broader, so that they began to show narrow ridges, separated by small ravines radiating from the summit, like the ribs of a half-opened umbrella, as described by Junghun when speaking of the outer slopes of the greater mountains.

Active, Dormant, and Extinct Volcanoes.—In the history of all large active volcanoes there occur periods, of greater or less duration, and of more or less frequency, in which the activity ceases. The volcano may be said to be *dormant* during those periods. When the activity has altogether ceased the volcano is said to be *extinct*. It is, however, not very easy to decide upon the entire extinction of volcanic activity at any place. Vesuvius was evidently dormant during all Roman history, down to A.D. 79. The Monte Somma is part of the ruined wall of the original crater, which must thus have been dormant for at least 600 or 700 years, and perhaps much longer.* It has been active ever since, with greater or less intervals, two of the greater amounting to 130 and 167 years. But, at a distance of 120 miles, in the centre of Italy, rises Mount Vultur, a volcanic cone, with its crater now a lake,† and some gaseous exhalations still proceeding from it. This volcano seems to have been much as it is now when it was the haunt of Horace in his youth, and there is no tradition of any eruption from it. Is it really an extinct volcano, or only dormant?

* See Daubeny's *Volcanoes*, 2d edition, p. 215, etc.

† Daubeny, p. 185, etc.

To come a little nearer home, we have in the Puy de Dôme district of central France groups of volcanic cones and craters, with streams of lava still uncovered, rough and scoriaceous, some of these running near the bottom of existing valleys, others cut through by these valleys and left at various heights, which show the different depths to which the valleys had been cut while the volcanic eruptions were going on.* Recent as some of these volcanic cones and lava streams appear, we can hardly look upon the volcanoes as other than extinct, and as having been so even in the time of Cæsar, and probably long before. But in this same region there are volcanic mountains of a much more ancient date, such as the Mont Dor and the Cantal, the lava streams from which now form plateaux on the summits of the hills, while their craters have long disappeared, and only the basal ruins of their cones remain. These must have been extinct before those of the Puy de Dôme chain commenced activity, yet the fact that the latter broke out in the neighbourhood of the Mont Dor shows that the volcanic force had been only dormant there. These great periods of quiescence in volcanic activity give us a lively impression of the length of time required for the piling up of a great volcanic mountain. When we recollect the vast bulk of Etna, the summit of which rises to a height of 10,872 feet above the sea, while its base would spread over one of our smaller counties, and that it has been accumulated by the slow ejection of ashes and out-pouring of lava streams, one of which, still bare upon the surface, we know to have flowed more than 2200 years ago,† we can only look upon 2000 years as but a small portion of the time which has elapsed since the commencement of the process.

The well-known valley, called the Val del Bove, which has been scooped out on the side of Etna, would take in Vesuvius and Monte Somma, and almost conceal them from sight. Yet it is quite possible that the materials removed to form the Val del Bove took as long a period for their formation as Vesuvius itself, in the history of which intervals of quiescence, varying from 130 to 600 or 700 years at least, are known to have occurred. Yet in the beds on which part of Etna rests, there are sea-shells of the same species as those which now inhabit the Mediterranean ; and in parts of Sicily such shells occur in rocks now 3000 feet above the sea. The mode of formation of the great volcanic cone, which has been reared over those buried remains, gives to still existing species an antiquity of enormous duration.

Geographical Distribution of Volcanoes.—For an adequate idea of the manner in which active and extinct volcanoes are distributed over the globe, the student will find it best to consult a special map, such as those of Mr. Scrope and Dr. Keith Johnston, already referred to. A little examination of the map will show him that all volcanoes

* See Mr. Poulett Scrope's *Volcanoes of Central France*, 2d edition. † Daubeny, p. 282.

rise either on islands, or on maritime parts of continents, or near some body of inland water; and that, while there are isolated volcanoes or widely separated groups of volcanoes, yet the general tendency is towards a linear arrangement. The vast Pacific Ocean is girdled with a more or less continuous series of volcanoes, running from New Zealand, by the Friendly Islands, New Guinea, the Sunda and Philippine Isles, to Japan; thence by the Kurile Isles to Kamtchatka, and across through the Aleutian Islands to North America; and then southwards along the western borders of that continent to the farther end of the Andes. In the Atlantic and Indian Ocean basins, on the other hand, the volcanoes are scattered at wide intervals over the oceanic area, and not along its margin.

If we take cognisance of the extinct volcanoes, and of the still older contemporaneous trap-rocks (which, as we have seen, are ancient volcanic rocks), we find that there is probably no great region of the earth's surface where volcanic activity is either not manifested now, or has not been manifested at some former period. So far as geological evidence can guide us, we have no reason to believe that there has ever been any epoch in the earth's history when volcanic action has not been displayed. The areas of its activity have constantly shifted; the same region, after ages of quiescence, has again been disturbed, and again has lapsed into quiescence. But though it has moved from place to place, it has never ceased to show itself. Nor does geological evidence lead us to conclude that there has been any diminution in the activity of the volcanic forces during the past history of the earth. It is quite true, as Sir William Thomson has urged, that the total amount of energy in the earth has decreased. But we can also well believe that volcanic eruptions, through the increased resistance of a thickened crust, may be fully as momentous in their effects now as they were in early geological times, just as (to use the homely simile once employed by Sir William himself in a conversation with the writer) the last spurt ejected by a boiling pot of porridge, after removal from the fire, may be as large or larger than any that preceded it. The time must no doubt come when volcanic eruptions will become weaker, until they wholly cease. This must happen whatever be the nature of the internal changes whereby volcanic action is excited, whether, with Sir H. Davy, we assume that action to be induced by the oxidation of unoxidised metals, or, with most geologists, by the expansive and explosive effects of steam, produced by the access of water to still highly-heated fluid portions of the earth's interior. The secular diminution of the total amount of energy from which volcanic phenomena arise makes it certain that these phenomena will eventually die out of the category of active geological causes.

CHAPTER XX.

UNDERGROUND CHANGES EFFECTED UPON ROCKS.

IN the present chapter we shall direct the student's attention to the nature and cause of the changes which are wrought upon rocks below ground by those subterranean forces, of which we have now studied the superficial effects, in elevation and subsidence of land, in earthquakes, and in volcanoes. In the section of this Manual devoted to Petrology, an account has been given of most of the facts of which we have now to consider the theoretical explanation. The subject may be conveniently treated under the following subdivisions:—1. Expansion and Contraction of Rocks. 2. Foldings, Contortions, Fractures, and Cleavage of Rocks. 3. Metamorphism. 4. Concretions and Mineral Veins.

1. Expansion and Contraction of Rocks.

That portions, at least, of the earth's interior are in a state of incandescence, and that other portions, if not actually fluid, must be intensely hot, are facts of which proof has been submitted in the foregoing pages. It has been ascertained experimentally that rocks expand on being heated, and contract on cooling.

Bischof has made some important observations on the contraction of igneous rocks as they pass from a fluid or glassy state to a consolidated condition.* He experimented on basalt, trachyte, and granite, and got the following results:—

	Volume in the state of glass.	In crystalline state.
Basalt . . .	1	0.9298
Trachyte . . .	1	0.9214
Granite . . .	1	0.8420
	In the fluid state.	In crystalline state.
Basalt . . .	1	0.896
Trachyte . . .	1	0.8187
Granite . . .	1	0.7481

From this it would appear that granite contracts 25 per cent, or a quarter of its volume, in passing from a fluid to a crystalline state, and 16 per cent in passing from a glassy to a crystalline state. These

* D'Archiac, vol. iii. p. 598.

effects must have had a great importance "when the primary granites were first cooling," says M. D'Archiac; but their importance seems still greater to geologists who are examining the broken and contorted rocks on the flanks of existing granite chains, and the phenomena of intrusion met with in such situations.*

M. Deville † and M. Delesse arrive at results rather different from Bischof's, and the latter gives the following table as comprising the limits within which the several rocks mentioned contract on passing from a fluid to a solid state.

Granite, leptynites, quartziferous porphyries, etc.	9 to 10 per cent.
Syenitic granite, and syenite	8 to 9 ,,
Porphyry, red, brown, or green, with or without quartz, having a base of orthose, oligoclase, or andesite	8 to 10 ,,
Diorites and porphyritic diorites (greenstones) .	6 to 8 ,,
Melaphyres	5 to 7 ,,
Basalts and trachytes (old volcanic rocks) . .	3 to 5 ,,
Lavas (volcanic and vitreous rocks) . . .	0 to 4 ,,

M. Delesse sums up his results as follows:—

"When rocks pass from a crystalline to a glassy state, they suffer a diminution of density which, all things being equal, appears to be greater in proportion to the quantity of silica and alkali, and, on the contrary, less in proportion to that of iron, lime, and alumina, which they contain. In arranging the rocks in the order of their diminution of density, those which we regard as the more *ancient* are generally among the *first*, while the more *modern* are the *latter*; and in each case their order of diminution of density is almost exactly the inverse of their order of fusibility." M. D'Archiac remarks that if granite contracts on cooling only 10 per cent, and that there be a thickness of 40,000 metres of it in the crust of the globe, crystallisation alone would diminish the terrestrial radius at least 1430 metres, and consequently alter the form and rapidity of rotation of the earth. Such speculations are practically useful only in a negative sense, as showing the great improbability of anything like a shell of 40,000 metres having cooled and consolidated at once in the crust of the earth during, at all events, any of the known geological epochs.

According to some experiments, made in America,‡ to ascertain the amount of expansion and contraction in different kinds of building-stones, caused by variations of temperature, it was found that in fine-grained granite the rate of expansion was ·000004825 for every degree

* Some doubt has recently been cast upon these results. See D. Forbes, *Chemical News*, vol. xviii. p. 191.

† *Bul. Soc. Geol. France*, 2d ser. iv. p. 1312.

‡ By Colonel Totten. Silliman's *Americ. Journ.* xxii. 136. Quoted by Lyell, *Principles*, vol. ii., p. 235.

Fahr. of increment of heat, in white crystalline marble it was ·000005668, and in red sandstone ·000009532, or about twice as much as in granite. If this ratio of expansion should be established for underground rocks, "a mass of sandstone, a mile in thickness, which should have its temperature raised 200° Fahr., would lift a superimposed layer of rock to the height of 10 feet above its former level." "But," continues Sir Charles Lyell, from whom these remarks are quoted, "suppose a part of the earth's crust, 50 miles in thickness, and equally expansible, to have its temperature raised 600° or 800°, this might produce an elevation of between 1000 and 1500 feet. The cooling of the same mass might afterwards cause the overlying rocks to sink down again and resume their original position. By such agency we might explain the gradual rise of part of Scandinavia, or the subsidence of Greenland." *

2. Foldings, Contortions, Fractures, and Cleavage of Rocks.

The manner in which rocks, originally horizontal, have been plicated on the great scale, contorted on the small scale, fractured, displaced, and cleaved, has been described in Chapters VII., VIII., IX., and X. These changes are obviously the result of those subterranean movements which have been considered in Chapters XVII., XVIII., and XIX. We are now to inquire whether any law or mode of operation can be determined according to which these changes are brought about.

That the contortion of rocks is due to lateral pressure was long ago proved experimentally by Sir James Hall. A little reflection will show us that if the bulk of the globe is slowly diminishing from secular refrigeration, the result must necessarily be the contortion of the rigid inelastic outer portion. Or, if an extensive subsidence takes place, contortion must necessarily accompany it. As Mr. J. M. Wilson has tersely expressed it, "*Contortions* are the inevitable result of the *subsidence* of a *curved* surface." † The problem, however, is much complicated in any given example by the great variations in the structure of the earth's crust, and the diversities of the resistance offered by different rocks. We may be confident that the crumpling of a great belt of rocks could only be brought about by the subsidence of a large area, the immense weight of which, as it sank, squeezed and contorted the rocks. Yet the local amount of contortion may have been continually modified by the texture and structure of the rocks themselves. Contortions, on a minor scale, have often been produced by merely local causes, such as the falling in of the roof of some subterranean cavity, or the intrusion of igneous rock.

Fractures must frequently accompany contortion. But it is a fact

* Lyell, *loc. cit.*

† *Geol. Mag.* v. p. 206.

that, as a rule, a much contorted region is not also greatly faulted;* while, on the other hand, a district which is much faulted is commonly pretty free from contortions. There must, therefore, be some kind of opposition between the two operations, by which contortion and faulting are produced. If the subsidence of a curved surface must inevitably produce contortions, then its elevation must give rise to fractures and faults. "*Faults*," to quote again from Mr. Wilson's excellent little paper, "are the inevitable result of the *elevation* of a *curved* surface." Instead of having to go into less space, as in subsidence, rocks, when elevated, have to occupy more room; and as they are not elastic, they can only do so by a system of cracks. Those fractured pieces which are broader at the bottom will rise farther than the other pieces which have a narrower base, or, in other words, the latter will sink relatively to the former.† Hence the dip or hade of a fault must be, as we have seen, in the direction of the area which has sunk, or away from that which has risen. As in the case with contortion on a minor scale, so with the numerous small faults met with in strata, we must often take into account local causes as sufficient to account for them, though the general law holds true that the great faults are due to elevatory movements.

Mr. Wilson has examined this question mathematically, and it may be useful to give here the conclusions at which he has arrived. He says:—"The following are the results I have obtained, on the supposition that a circular area of the earth's surface, whose diameter subtends an angle of 2θ at the centre of the earth, is depressed, so as to maintain a spherical form (of course a portion of a larger sphere) to a depth of (a) miles in the centre of the depressed region. The calculation may be relied on as true within a few yards.

TABLE OF COMPRESSION IN YARDS,
For an arc of 2θ, depressed to a depth of a; radius = 4000 miles.

	$\theta = 5°$	$\theta = 10°$	$\theta = 20°$	$\theta = 40°$
$a = 1$ mile . .	121	211	354	800
$a = 2$ miles . .	189	408	745	1625
$a = 4$ miles . .	355	788	1584	3214
$a = 8$ miles . .	598	1527	3213	8529
Linear distance across depressed area	345 miles	690 miles	1380 miles	2760 miles

"The inspection of this table will show that the known rising and sinking of

* Unless, of course, it has been exposed to disturbance after the contortion. The remarks in the text refer to large powerful faults. † See *ante*, p. 212, and Wilson, *loc. cit.*

large areas of the earth's surface *is adequate* to produce much compression and extensive faults. But this table can be made to yield some other important results. When the geological structure of a country is pretty well known, the *amount* of contortion—*i. e.* the difference between the direct distances of two distant points, (1) measured along a circular arc, (2) measured along strata,—may be approximately known. And if this contortion appears not to be due to the intrusion of local igneous rocks, and does appear to be due to depression, we get a means of calculating to what depth the strata sank when those contortions were being produced." *

It may seem paradoxical, yet on reflection will be found to be true, that depression may be actually the origin of elevated mountain chains. If the resistance offered by the superincumbent descending mass be less, as we might expect, than that offered by the stationary parts of the earth's crust on either side of the subsiding area, the enormous pressure will tend to relieve itself by the rise of any tract or belt of country where the amount of resistance is least. It is a fact that mountain-ranges usually consist of crumpled and contorted rocks.

Cleavage has been described in Chapter X., and referred to the action of lateral pressure upon rocks. This pressure must often arise in the course of those movements of upheaval and subsidence, which have been referred to. When the rocks, enormously compressed from two sides, cannot get sufficient relief by fracture or crumpling, their component particles arrange themselves with their longer axes at right angles to the direction of compression. Hence a new fissile structure is developed. A similar structure may be artificially produced by pressure upon wax, clay, etc.†

3. Metamorphism.

In the Classification of Rocks, given in Chapters IV. and V., a distinct series was described under the title "Metamorphic Rocks," that is, rocks which had been altered or "metamorphosed" from their original condition into one quite different. Again, in Chapters X., XII., and XIII., further allusions to and descriptions of metamorphic rocks and metamorphism required to be given. We have now, however, to look more in detail at the nature of the process or processes by which the alteration or metamorphism has been produced.

Chemists are accustomed to speak of metamorphic changes as produced by one of two modes—1st, In the dry way, and 2d, in the wet way. In the former we have to consider the effects of heat, either in fusing rocks and producing new chemical reactions within them, or in hardening them, and inducing within them some texture or structure different from what they had before. The contact of an intrusive igneous rock with sandstone, shale, limestone, coal, etc., is an instance of the production of metamorphism in the dry way.‡ In the wet pro-

* J. M. Wilson, *Geol. Mag.* v. p. 207.

† See *ante*, p. 223.

‡ See *ante*, pp. 261, 268.

cess we see how water, either with or without a high temperature, and charged with alkaline or other re-agents, has removed some elements from rocks and deposited others in their place. The conversion of common limestone into dolomite is an illustration of this process. This division, however, is, after all, somewhat arbitrary, for even in the so-called dry way, water or steam may often play an important part; while, on the other hand, the action of heated gases and vapours could hardly be properly placed under either of the two methods. We shall better describe the nature of metamorphism if we term it a process wherein heat and chemical action in many various ways have gradually changed the internal texture and composition of rocks.

Pseudomorphic Metamorphism.—An attentive study of what takes place upon the rocks at or near the surface enables us to realise in some measure the metamorphic changes which must be going on at greater dêpths. Rain-water falls to the earth nearly in a state of chemical purity, though it does contain minute quantities of carbonic acid, and other substances found in the atmosphere. When, however, after sinking into the earth, the water rises again in the form of springs, it is no longer pure, but always holds a greater or less amount of mineral matter in chemical solution. The carbonic acid which the rain abstracts from the atmosphere, and still more from the vegetable mould through which it sinks underground, enables the water to re-act upon the rocks underneath. It extracts from them such substances as are either soluble in water alone, or in water containing carbonic acid. "These substances enable the water to effect further decompositions, or to give rise to new formations, on its penetrating deeper. But this action does not consist merely in forming a solution of some of the mineral substances existing in rocks, but also in producing the decomposition of silicates by the aid of the carbonic acid in the water. Not only do rocks lose more or less of their constituents by the action of water, they also suffer changes in their composition. The knowledge of these changes, and their laws, constitutes the basis upon which chemical geology must be founded," and forms the groundwork of all proper study of metamorphism.*

The replacement of one mineral by another, owing to the chemical action of percolating water, while the original form of the crystal or mass is retained, has been already referred to under the name of *pseudomorphism*.† It is this replacing action which is concerned in the process of *petrifaction;* and perhaps a more vivid idea of this kind of metamorphism may be gained by the beginner from an examination of petrified animal and vegetable structures than from that of inorganic substances.

Petrifaction.—Living animals and plants, by means of their

* Bischof, *Chemical Geology*, vol. i. p. 53.

† See *ante*, p. 50.

fluids, take up, and convert into their own substance, silica, lime, magnesia, soda, potash, phosphorus, carbon, iron, etc. This they do in obedience to the organic forces, those chemico-biological actions, the assemblage of which we call *life*. When life no longer exists, and its forces cease to act, the substances of animals and plants become obedient to inorganic laws, and their mineral portions are acted on just in the same way that other mineral matters are affected. Wood may either lose certain proportions of its constituents, and become more and more *carbonised*, or it may lose the whole of them particle by particle, and as each little molecule is removed, its place may be taken by a little molecule of another substance, as silica, or iron pyrites, and it may thus become entirely *silicified* or *pyritised*. Bones and shells, and other hard parts of animals, consisting mainly of phosphate and carbonate of lime, may, in like manner, have the proportions, or the state of aggregation, of their constituents altered more or less completely, or may have their substance gradually but entirely replaced by another substance, more or less different from the former. In this way, parts consisting originally of carbonate of lime may either have the organic cellular structure obliterated by assuming a crystalline structure, or may become embedded in a crystalline covering of carbonate of lime, or that mineral may be converted into sulphate of lime, or replaced by silica, iron pyrites, or other substances, the cellular structure being in each case either preserved, or partially or entirely obliterated.

The student will find in the great work of Bischof a storehouse of facts in this branch of geology. The following extracts will show the nature and value of his researches:—"Stein converted a crystal of gypsum into carbonate of lime by leaving it for several weeks in contact with a solution of carbonate of soda, at a temperature of 122° F." The sulphuric acid of the gypsum united with the soda to form sulphate of soda, which was dissolved and carried away by the water, and the lime united with the carbonic acid. "All the striæ upon the curved surfaces of the crystal were perfectly retained, as well as the cleavage in the direction of the T-planes. In these artificial pseudomorphic processes, the form of the original substance is retained only under certain conditions, the most essential being slow action; and the same holds good in nature. If these conditions are not fulfilled, the original form is lost."

"In the analysis of a mineral in which changes have already commenced, especially by the addition of new constituents in very minute quantities, it is not unlikely that they may be considered as accidental and deducted. Since, however, alterations seldom take place merely by addition, but more frequently by loss of constituents, it is likewise requisite that the quantities lost should be added to the analytical results.

"There are sufficient grounds for considering andalusite to be a pure silicate of alumina, although previous analyses have pointed out, besides these two essential constituents, potash, lime, magnesia, oxides of iron and manganese, and water. Andalusite is converted into mica, in which change a part of the alumina is removed; potash, magnesia, and peroxide of iron, being introduced into its place. One of these bases is always found in andalusite, sometimes several of

them together; and it may therefore be inferred that this mineral, as usually met with, is already in a state of incipient alteration. No other alteration of andalusite is known besides that into mica, except that into steatite. The latter change presupposes not only a partial but a complete disappearance of the alumina, and its replacement by magnesia. These examples will suffice to show the importance of the minute quantities of substances present in minerals, and generally considered as accidental. These substances, which are troublesome to the chemist, because he cannot introduce them into the chemical formula, acquire significance when compared with the constituents of the pseudomorphs resulting from the alteration of the mineral in question. They then no longer appear as accidental, but indicate the transition of one mineral into others, and lay before us clearly the greater part of the conversion process.

"It is possible that several changes may frequently have taken place before the last product was formed. In the alterations of complex minerals, especially silicates containing several bases, there are certainly transitions in most cases, and sometimes a long series. Thus Cordierite * is the starting point of a whole series of alterations, finally ending with Mica; while Fahlunite, Chlorophyllite, Bonsdorfite, Esmarkite, Weissite, Praseolite, Gigantolite, and Pinite, are remains of Cordierite in pseudomorphic conditions. Inasmuch as the minerals between Cordierite and Mica are only transition products, they cannot be regarded as individual species." †

"Pseudomorphs furnish us with a kind of knowledge which we have no opportunity of deriving from any other source. It will scarcely ever be possible to convert augite, olivine, or hornblende, etc., into serpentine, in our laboratories. But when we find serpentine in the form of these minerals, this fact is a sufficient evidence that such a conversion can take place; and if in any given instance there are geognostic reasons for the opinion that one or other of these minerals, or even several together, have furnished the materials for the formation of serpentine, there is a high degree of probability that such a change has actually taken place.

"If a crystalline mineral can, under certain conditions, be converted into another, whether with or without retention of form, then the same mineral in an amorphous state would certainly suffer the same change when placed in the same circumstances." From this he shows that amorphous masses of serpentine may be formed from amorphous masses of augite, etc., and also that, in some instances, the original form of a crystalline mineral may be destroyed together with its substance, and the new mineral occur in its own crystalline form. He concludes the subject thus:—

"The importance of the pseudomorphic processes, and the error of those who regard them as having but little connection with the changes of rocks, is sufficiently shown by the total disappearance of previously existing substances in veins. I consider that the entire removal of fluor and calc spar from a whole series of veins, and the introduction of an equal quantity of quartz in their place, is a matter of vast importance. To what enormous spaces of time do we come when we reflect upon the periods during which the fluor and calc spar were introduced into these fissures, and then the periods during which they were again removed by water, and quartz substituted in their place! And yet this happened after the formation of the rocks in which these fissures occur. If we imagine similar processes to have taken place in the rocks themselves, and extending over not only both these periods but the entire space of time since their formation, we shall be

* Cordierite is a mineral composed of a silicate of alumina, combined with two atoms of silicate of magnesia.

† If further well-considered researches establish these conclusions, it will have a wonderful effect in simplifying the important science of mineralogy, and in applying its results to the formation of various kinds of rocks.

compelled to admit that inconceivably stupendous changes have taken place. After such considerations, the conversion of extensive masses of rock by the action of water alone into steatite, talc, serpentine, kaolin, etc., cannot appear in the slightest degree strange."*

By these pseudomorphic processes large mountain masses of limestone have been converted into dolomite; and not merely has the composition of the rock been changed, but its texture also, and even all trace of stratification has been obliterated. Some wonderful illustrations are furnished by mountains of the Eastern Alps.

Influence of Pressure on Metamorphism.—We can imitate in the laboratory a number of the metamorphic changes which take place in nature. Yet the latter have, as a rule, been produced under circumstances which we cannot command. There is, as Bischof has pointed out, the element of time. Many of the changes are so infinitesimally small and gradual, that we cannot hope to reproduce them. Again, they have often taken place under the pressure of hundreds and thousands of feet of superincumbent rock. The influence of pressure in modifying chemical re-actions was long ago pointed out, for the first time, by Hutton, and experimentally proved by Hall.† When limestone is heated sufficiently in a kiln or fire it parts with its carbonic acid. But Hall showed that if the same heat is applied under great pressure, the rock may be converted into a crystalline marble, or even fused without the loss of its carbonic acid. He argued, therefore, that the effects which heat produces upon rocks at great depths may be very different from those which it ordinarily produces at the surface.

Influence of Heated Water.—All rocks are more or less permeable by water, and water circulates through the rocks, at least as deep as man has been able to penetrate into the crust of the earth. We have seen that the temperature increases regularly as we descend beneath the surface. Hence, at no great depth, the rocks must be traversed by warm water, a condition most favourable for chemical changes. It is not necessary, however, for the accomplishment of such changes that the temperature should be very high. Mr. Sterry Hunt‡ argues, that from the occurrence of graphite or unoxidised carbon in the metamorphic schists of Canada, the heat could never have been very intense, or at all approaching the melting point of the silicates. He shows that water at 212° F., containing solutions of alkaline carbonates, would be sufficient for the solution even of silica, and the decomposition of silicates and the formation of garnet, epidote, and chlorite, and other silicates of lime, magnesia, and iron; and that, if the temperature were raised to 480°, it might suffice for the production of chiastolite, staurolite, etc., and felspathic and micaceous silicates generally. Such temperatures may readily be supposed to be imparted to portions of the earth's

* Bischof, *Op. cit.* vol. i. chap. ii.

† See the *Theory of the Earth*, vol. i. chap. i.; and *Trans. Roy. Soc. Edin.*, vol. vi. p. 95.

‡ In the Reports of the Geological Survey of Canada for the years 1853-6.

crust, either locally, by the intrusion of granite, or over wider areas, when any part of what may now be the surface was as deep as from 10,000 to 20,000 feet below the surface.

Production of Foliated Rocks by Metamorphism.—Foliation has been already (Chapter X.) described as a texture superinduced upon stratified rocks, the lines of lamination or of cleavage having been replaced by a re-arrangement and crystallisation of the ingredients in lines of folia. That this is not the original condition of the rocks, but a metamorphic one, is shown by the intercalation of unaltered or but little altered beds of grit, greywacke, or sandstone, and by the occurrence of organic remains, sometimes in the foliated rocks, sometimes in the quartz rocks and limestones between and beneath them. In foliation, the minerals (chiefly felspar, quartz, and mica, talc or chlorite) have segregated in different layers, which alternate with and merge into each other.

Though we can conceive theoretically how a mass of stratified rock, buried under later formations and depressed to a great depth, so as to be brought within the action of subterranean heat, may undergo great internal changes, it is not perhaps very easy to follow the various steps of the process, wherein the different minerals were separated into distinct folia. We must bear in mind that there were necessarily original differences in the composition of the various strata which have been foliated. Some were more siliceous, others more argillaceous, others more calcareous. So that, even if the process of metamorphism went on uniformly over the whole mass of strata, some beds, being much more easily acted on than others by heated alkaline water (or other metamorphic agent), would undergo a greater change. But in all probability the metamorphic process was far from uniform in its operation. The rocks would differ from each other in their conductivity of heat and in their perviousness to water, while the quantity of water passing through them may have been irregular, and without relation to the relative capacity of the different rocks to receive it.

It appears that foliation is the result of a long series of reactions, and that these have been chiefly carried on by heated water charged with alkaline solutions. We have seen that foliation coincides either with stratification or with cleavage. The water, in short, followed the most marked lines of division of the rocks, and flowing or percolating along these lines decomposed the substance of the rock, dissolving and removing some minerals and re-depositing others. Purely siliceous rocks would be little liable to change from this source ; hence we find the bands of grit or sandstone among mica-schists still comparatively unchanged (see Fig. 86), and the bedding, and even the worm-burrows and ripple-marks on quartz rock, still remain. But in argillaceous rocks, such for instance as were formed from the waste of others in

which felspar was a main constituent, the conditions for alteration were eminently favourable. The silicates were decomposed, and the liberated silica was deposited along the divisional planes, whether of bedding or cleavage. Felspar we know to have been converted into mica and quartz,* and we may conceive that a mass of highly felspathic strata, such as many of the palæozoic rocks are, might in the same way be resolved into these two minerals, the segregation taking place in folia corresponding to the lines along which the water passed.

Among the foliated rocks a gradation can be traced from clay-slate through mica-schist and talc-schist into gneiss, and from gneiss into granite. The metamorphic process can thus, as it were, be seen in all its stages. In some rocks we seem to see merely its beginnings. In others we trace a further development of the internal rearrangement, until in mica-schist the foliated texture is fully developed. In gneiss, though the folia still remain, foliation begins as it were to pass into a more irregularly crystalline structure, which reaches its perfection in granite. In this metamorphic series, therefore, clay-slate stands at the one end and granite at the other.

Relation of Granite to Metamorphic Rocks.—In a former part of this Manual the petrological relations of granite to gneiss, mica-schist, and other rocks, was described,† and it was shown that in some cases there could be little doubt that the granite itself is a rock of metamorphic origin. A regular gradation may be observed in many highly metamorphosed districts, from porphyritic granite, in which there is not the slightest trace of any lamination or parallel arrangement of the minerals, through tracts where such an arrangement becomes first obscurely and then strikingly manifest, into other tracts where the whole mass of the rocks is arranged into beds and layers of different constitution, some of which might be called "gneiss," others "mica-schist," and with which beds even of "crystalline limestone" are alternated.

There are, however, other tracts in which the granite occurs in larger mass, in which there is very little trace of any gradation from the granite into the surrounding rocks, even when these surrounding rocks do assume the form of mica-schist and gneiss. The granite which runs for seventy miles S.S.W. of Dublin, described in Chapter XII., is of this character. It cuts variously through beds of clay-slate, which are interstratified with thin fine-grained siliceous grits. The alteration in the clay-slates in the direction of the granite first becomes perceptible at a distance of a mile or two from the line where the granite reaches the surface, and becomes more marked, until in immediate contact with the granite there is perfect mica-schist, with crystals of garnet, of andalusite or staurolite, and other similar minerals.

* Bischof, ii. p. 172.

† Chapter XII.

Here, however, as even in highly metamorphosed districts at a distance from granite, the purely siliceous bands of fine-grained grey gritstone, from half-an-inch to an inch in thickness, which are interstratified with the schists, are unaltered, except by induration, exhibit no signs of micacisation, and do not differ from the grit-bands interstratified with the unaltered clay-slate at a distance from the granite. Moreover, the mica-schist itself varies in character in different layers, evidently in consequence of those layers differing from each other originally in mineral character. The half-formed crystals of staurolite (or andalusite), for instance, which occur under Killiney Hill, near Dublin, only occur in certain layers in which the substances happened to exist in the proper proportion to form them, while in intermediate layers, where that proportion did not exist, no such crystalline forms are apparent. These layers are in many cases abruptly cut off by the mass of the granite, or by the granite veins that penetrate them, much in the same way that aqueous rocks are cut off in other places by masses or veins of trap. Even hand specimens may be procured in abundance, where the two kinds of rock are separated by a sharp line of division, without the slightest trace of gradation from one to the other.

In such cases it is evident, that, whether or not the granite has been originally formed by the metamorphism of other rocks, it has certainly, in a fluid or pasty condition, invaded and altered the sedimentary rocks against which it is now found, and that here it cannot be regarded as other than an igneous rock, though of course one which differs widely from an ordinary trap-rock or lava.

Depth at which Granite was formed.—In a very important paper* on the Microscopical Structure of Crystals, Mr. Sorby shows that it is possible to arrive at some remarkable conclusions as to the temperature and depth at which the crystalline particles of granite and other igneous rocks were formed. Crystals formed from warm fluid solutions are often full of cavities which contain some of the fluid in which they were formed. If these cavities are not completely filled with the fluid, the vacuity may be taken as a measure of the shrinking of the fluid during cooling, and we may then calculate the amount of heat requisite to expand the contained fluid so as to completely fill the cavity, and may thus arrive at a knowledge of the temperature of the fluid at the time the crystal was formed. But crystals formed in *fluids by fusion* are also full of cavities, which contain some of the fused matter, now become solid stone, together with vacuities, the relative size of which enables us to calculate the amount of heat that would melt and expand the contained stone or glass, so as to fill up the whole cavity. The effect of pressure has of course to be taken into account; the

* *Quart. Jour. Geol. Soc.* vol. xiv. p. 453.

greater the pressure the greater might be the temperature of consolidation requisite for the production of cavities and vacuities in the crystals, so that the relative sizes of these, when the possible temperatures of consolidation are taken into account, give us an idea of the pressure and possible depth under which the rock was consolidated.

Mr. Sorby applies these principles to the examination of many igneous rocks, lavas, traps, and granites, and proves from them the igneous origin of all, with this remarkable result, that the fluidity of the more superficial lavas and traps was a more purely igneous one than that of the deeper seated traps and granites. The blocks ejected from Vesuvius during eruption contain water, while the lavas do not; and the crystals of the Cornish elvans, and the Cornish and Scotch granites, contain both fluid and stone cavities, proving the presence of water, and perhaps also of gas, as well as the existence of great heat. Mr. Sorby concludes :—

"On the whole, then, the microscopical structure of the constituent minerals of granite is in every respect analogous to that of those formed at great depths, and ejected from modern volcanoes, or that of the quartz in the trachyte of Ponza, as though granite had been formed under similar physical conditions, combining at once both igneous fusion, aqueous solution, and gaseous sublimation. The proof of the operation of water is quite as strong as of that of heat." In some coarse granites it is impossible to draw a line between them and veins in which crystals of felspar, mica, and quartz, seem to have been formed from solutions without any actual fusion. If granite and elvan finally consolidated at a temperature not exceeding about 608° F., the elvans of Cornwall must have been formed under a pressure equal to that which would have been exerted by a thickness of about 40,000 feet of rock, those of the Highlands of Scotland one of 69,000. Calculations unite in giving these conclusions :—

The granites of the Highlands indicate a pressure of 26,000 feet more than those of Cornwall.

The elvans of the Highlands, one of 28,700 feet more than those of Cornwall.

The metamorphic rocks of the Highlands, one of 23,700 feet more than those of Cornwall.

If the temperature of consolidation was higher, the pressures must have been greater. Mr. Sorby does not mean in his conclusions to point out the absolute depths at which the rocks consolidated, since the pressure they were subjected to might arise in part from the impelling force acting from below against the superincumbent mass.

Cycles of Metamorphism.—If we look upon *all* aqueous rocks as in some shape or other *derivative* rocks—and this is a conclusion from which we cannot escape—we must regard them as either mediately or immediately derived from igneous rocks. With regard to the mechanically formed aqueous rocks this is obviously true, because, if we trace to their original source the silica and alumina, the quartz, the felspar, and the mica of which they are made up, we must eventually arrive at some igneous, most probably some granitic, rock as their parent. But even as regards the lime, soda, and magnesia, of all the chemically and organically formed aqueous rocks (setting aside the carbonaceous rocks), we are compelled to suppose that the water first derived those minerals from the decomposition of such igneous rocks as contained them. Speaking generally, then, it need not surprise us to find

materials that had once been fused reduced again to that condition. It is true, that the matters that acted as a flux to the silica and alumina of the igneous rocks may have been washed out and removed more or less completely from the debris of those rocks which form our sandstones and clays; but purely siliceous sandstones or pure clays are comparatively rare and in small quantity, and if the rocks around them and enclosing them were remelted, they would soon become mingled with the other rocks which retain their basic constituents, or consist more or less entirely of basic materials, and thus again might ordinary igneous rocks be formed. There can, therefore, be nothing either unphilosophical or improbable in regarding the whole crust of our globe as consisting of materials passing through an endless cycle of mutations, existing at one time as igneous rocks, then gradually decomposed, broken up, separated out, sorted, and deposited as aqueous rocks, at a subsequent period metamorphosed, and ultimately re-absorbed into the igneous rocks. In this view, the most highly metamorphosed rocks would be those most nearly hovering upon the brink of re-absorption, and gneiss accordingly on the point of passing into granite, and in some cases perhaps undistinguishable from what we may conceive as originally-formed granite, no part of which has yet entered on this cycle of change.

Production of Pseudo-igneous Rocks by Metamorphism.—We have seen that metamorphic granite is the ultimate stage of that line of metamorphism which leads from clay-slate through mica-schist to gneiss. There is another line of metamorphism where highly felspathic sedimentary rocks, including even conglomerates, have been converted into crystalline and porphyritic masses, which at first sight would not be regarded as anything but true igneous rocks. Some remarkable examples of this kind occur in the Silurian and Old Red Sandstone districts of Ayrshire in Scotland. Near Girvan, a conglomerate, which in one place is well stratified, passes by degrees into a dull dirty green amorphous porphyritic rock, in which, after a little, even the more siliceous pebbles cease to be visible. This rock varies greatly in texture and composition. It is associated in the same district with serpentine, diallage-rock, diorite, and syenite.*

Metamorphism of Igneous Rocks.—Metamorphism is not confined to the aqueous rocks, but is probably equally active among the igneous rocks themselves, although there the processes are more concealed from us. Many rocks, which are now undistinguishable from true igneous rocks, may have been formed by a comparatively slight metamorphism of tuff, or other mechanical accumulation of materials, derived directly from igneous rock, and subsequently brought within

* This district has been surveyed in the course of the Geological Survey, and part of it is described by Mr. James Geikie, *Quart. Journ. Geol. Soc.*, vol. xxii. p. 513.

the influence of metamorphic action. Some real and originally formed igneous rocks may in like manner undergo metamorphoses, more or less complex. Some rocks, for instance, may have acquired a porphyritic texture by long-continued and comparatively gentle metamorphism, acting on previously compact trap-rocks. The same comparatively slight action has doubtless caused many once compact igneous rocks to become more completely crystalline, and in some cases generated new combinations, and produced mineral forms that did not exist in the original rock. These possibilities should be borne in mind when we are endeavouring to explain phenomena that otherwise are often difficult to understand. In metamorphosed regions, igneous rocks which would fall under the general class of greenstones or felstones, are much more completely, or much more coarsely crystalline, than similar igneous rocks in unaltered districts, and seem in some cases to have had not only their state of aggregation, but even their mineral composition changed, either by a re-arrangement of their constituents, or by the subtraction of some which they formerly possessed, or the addition of others which they did not. Other igneous rocks may occur in the same districts which have been intruded subsequently to the metamorphic action, and therefore have the same characters as when they occur in unmetamorphosed districts. Want of attention to this circumstance seems to have been one of the sources of the confusion which still is to be found in the nomenclature of the rocks found in igneous and metamorphic districts, and the multiplicity of the varieties introduced and named. All chemical, mineralogical, and microscopic descriptions of such rocks should be accompanied by careful geological descriptions of the neighbourhood of the locality from which they are obtained, special notice being taken as to whether the general mass of the surrounding rocks exhibits marks of metamorphism or not ; and all varieties derived from such districts should be admitted with great caution among those of unmetamorphosed igneous rocks.

In connection with this possible metamorphism of igneous rocks on a large scale, the contact metamorphism of igneous rocks, and the reaction of the enclosing rock on the igneous mass itself, is a subject of great interest, hitherto little investigated. Black basalt or dolerite, where it penetrates coal, is converted into the "white rock trap," described at p. 261, sometimes for a depth of several feet; and in many cases the metamorphism along the boundary of an intrusive rock is apparently about as great in the latter as in the rock which it traverses.

4. Formation of Concretions and Mineral Veins.

Not only have rocks had their substance altered by the removal or re-arrangement of their ingredients by metamorphism, but cavities, either original or subsequently formed in their mass, have been filled up with

new mineral compounds. In Chapters XIV. and XV. a description has been given of the way in which veins of minerals and mineral concretions occur in rocks. Such concretions as were not formed originally (as clay ironstone nodules were) along with the rock in which they are found, are due to the chemical action of percolating water. And even the contemporaneously-formed concretions have been subsequently affected by the same universal action. The ironstone nodules, for instance, are often found to have their internal cracks filled up with calc spar, sometimes with blende or galena—substances which were introduced by percolating water, long after the formation of the concretions. The chemical reactions which resulted in the formation of concretions of iron pyrites, chert, phosphate of lime, etc., will be best understood from the detailed descriptions of Bischof.

Between mineral veins and concretions there is a close analogy. A vein or veining is in many cases only a thread of an inch or two in length, and may be regarded as merely an elongated concretion. Such are many veins of quartz and carbonate of lime. From these tiny veins there is every gradation of size and substance, till we come to great metalliferous lodes or reefs, many yards broad and several miles in extent. If the student will refer to the geognostic account already given of mineral veins, he will see that, from the way in which the spars and ores occur together, there can hardly be any doubt that they have all been formed successively by variations of the same great process of infiltration. It seems clear that, whatever other agent may have been at work, water charged with mineral solutions has been the great agent here, as in other metamorphic processes.

It has been maintained that currents of voltaic electricity have traversed and are traversing the lodes, and have been largely instrumental in the deposition of the several ores.* Another explanation has been suggested by the results of metallurgical processes—viz., that the metallic ores met with in veins have been sublimed in fissures by the action of underground heat.† But the fact that the spars and vein-

* See an interesting paper by Mr. R. Weir Fox (*Trans. Royal Geol. Soc. Cornwall*, vol. iv.) on the "Electro-Magnetic Properties of Lodes."

† The following note on this subject is by Mr. Jukes:—"When walking across the Allenheads mining country after the meeting of the British Association at Newcastle, in the year 1838, a chimney, a mile long, built up the side of a hill near one of Mr. Beaumont's mills, in the county of Northumberland, was pointed out to me. It had chambers in it at intervals, and it was said that its expense was repaid in a few years by the quantity of lead deposited in these chambers, which would otherwise have been dissipated in the state of vapour into the atmosphere. As this happened so many years ago, I wrote to Mr. Sopwith, the eminent manager of Mr. Beaumont's mines, respecting it, and in answer I was informed by him that formerly 'large quantities of lead were carried off in the state of vapour and deposited on the surrounding land, where vegetation was destroyed, and the health of both men and animals seriously affected.' This led to various extensions of the horizontal or slightly inclined galleries in use at Mr. Beaumont's mines, and the quantity of

stones, which cannot be supposed to owe their existence to sublimation, are so intimately associated with the ores, leads us necessarily to assume one common origin for the whole, and as they are all products which might have been produced by infiltration, there seems no good reason to assign any other cause for their formation. It is open to question whether the metallic substances have been derived from the rocks adjacent to the veins, or from some other source. Probably both these sources have been available.

The remarkable relation which, as pointed out in Chapter XIV., often holds between the development of minerals in a vein, and the varying nature of the rocks through which the vein passes, may indicate either that the minerals were directly derived from these rocks, or that if they were carried up in solution from greater depths, the nature of the composition of the rocks on each side of the veins determined the deposition of the particular minerals in the veins themselves.

Supposed Connection between Igneous Rocks and Metalliferous Veins.—Whether or not an increase of temperature has been connected with the deposition of ores in veins, it is abundantly evident that the occurrence of igneous rocks has no connection with it. This supposition of a relation between igneous rocks and mineral veins seems partly to have sprung from the fact that igneous rocks also occur in veins, and partly from the other fact that metalliferous mineral veins often occur in districts which are partly composed of igneous rocks. It is obvious, however, that veins of igneous rock very seldom contain either spars or ores at all resembling those found in mineral veins, their contents being merely a rock mass, composed of imperfectly crystallised silicates. It is equally obvious that the occurrence of metalliferous mineral veins in districts partly composed of igneous rocks, is the consequence not of the igneous origin of such rocks but of their hardness and durability, the fissures in these rocks remaining open till they became the receptacles of spars and ores. The igneous rocks, like those of aqueous origin, were evidently consolidated, and much in the same state in which they are now, before they commenced to be fissured, and the infilling of the fissures is a yet more recent operation.

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lead extracted rapidly repaid the cost of construction. The latest addition of this kind was made at Allen Mill, and it completed a length of 8789 yards (nearly five miles) of stone gallery (or chimney) from that mill alone. This gallery is eight feet high and six feet wide, and is in two divisions widely separated; one being in use during such times as the *fume* or deposit (a black oxide of lead) is taken out of the other. There are also upwards of four miles of gallery for the same purpose connected with other mills belonging to Mr. Beaumont in the same district and in Durham, and further extensions are contemplated. The value of the lead thus saved from being totally dissipated and dispersed, and obtained from what might be called *chimney scrapings*, considerably exceeds ten thousand pounds sterling annually. It should be observed, however, that the mines of which these chimneys or flues are an appendage, are the largest lead-mines in the world, and that the royalties or freehold rights of mining belonging to Mr. Beaumont in the county of Northumberland alone, extend over more than a hundred square miles, in addition to extensive leasehold mines in the county of Durham.

"At the Ballycorns lead smelting works, near Dublin, a long chimney has lately been carried up the side of the hill for a distance of about a mile, the cost of the construction being repaid by the lead regained from it."

When the igneous rocks are of such a nature as not readily to afford open fissures, as is the case with the toadstone of Derbyshire, the Great Whin-sill of the Northern counties, and other similar rocks, their presence is obviously unfavourable to the continuity of wide metalliferous fissures. The toadstones, indeed, are mainly contemporaneous with the limestones. In the levels of some of the mines near Bakewell, there occur cavernous holes in the lower part of a bed of limestone, from which nodular masses of the toadstone, on which the limestone rests, have been excavated, in a more or less decomposed state. This shows that the limestone has been deposited on a rough surface of toadstone, and has enclosed these masses. It has also been proved that the same veins, which are rich in lead ore above a bed of toadstone, and seem to end entirely on coming down to it, are to be found in the limestone below it, with the same, or nearly the same, line of hade and direction, and the same contents as above the toadstone. In the same way, in the north, the veins lose their contents on coming down to the Great Whin-sill; but that the whin-sill was there before the formation of those veins is shown by the fact that the throw of the bed of whin-sill by these veins and faults is exactly equal and similar to the throw of the other beds.*

Successive Formation of Mineral Veins.—The mineral substances filling these veins usually occur in duplicate bands (see Fig. 117, p. 295), of which there may be a number of pairs. The material coating each wall of the vein is commonly the same on both sides, and each is covered by a series of similar layers, till they meet, or are only separated by a single distinct layer, forming the centre of the vein. It is evident, from this arrangement, that the filling of each vein must have been a long-continued process, of which each pair of separate deposits represents one of the stages. We may either suppose that the fissure received its full width at first, and was gradually filled up by those successive depositions, or, more probably, that it was widened at intervals, and that, between these repeated widenings the various mineral layers were deposited.

Connection of Mineral Veins with the Surface.—In some cases water-worn pebbles and other foreign substances are found in mineral veins, indicating the former connection of the fissures with the surface. On this subject the student will find some very interesting matter in the work entitled *Notes on the Geology and Mineralogy of Santander and Madrid*, by Dr. W. V. Sullivan and J. P. O'Reilly.†

The province of Santander is a mountainous district, composed of massive limestones, dolomites, and sandstones, belonging chiefly to the Jurassic and Cretaceous periods, but without a trace of any igneous rock. The rocks are often traversed by large contortions and faults, and the limestones and dolomites especially are traversed by many mineral veins, which contain ores of zinc in the greatest abundance, with the occasional occurrence of ores of lead, copper, iron, and other metals. The veins seem chiefly to be analogous to *gash* veins or *pipe* veins, and some of those in the limestones and dolomites are certainly of the latter class. In the Dolores mine, in the valley of the river Udias, a cave was discovered, the floor and walls of which were covered with "white ore," a pure hydrocarbonate of zinc, of snow-like whiteness, and in this, coated with the zinc ore, were found the bones of many of the animals which have most recently become extinct—bones of deer, three teeth of *Elephas primigenius* or Mammoth, the bones and teeth of a *Rhinoceros*, and many others. Dr. Sullivan gives chemical reasons for believing that the bones had suffered little from decay at the time in which they became enveloped in the ore. He also gives some interesting details of spars and ores, silicates as well as carbonates being observed in the act of formation, as they passed from the *fluid* through the *colloid* into the *crystalline* state.‡

* See the sections in Mr. Wallace's work, already cited.

† Published by Williams and Norgate, in 1863.

‡ *Op. cit.* p. 97, *et seq.*

It sometimes happens that these extraneous or surface-derived materials furnish us with evidence of the geological date at which the veins opened up to the surface, or, at least, communicated with some subterranean water-course, which was supplied with water from the surface. Mr. C. Moore, of Bath, has given an account of his discovery of many land and fresh-water fossils, belonging to the Liassic period, at depths of 270 feet in the mineral veins in the Carboniferous Limestones of the Mendips, and of parts of South Wales.*

Taking these facts in connection with the statements as to the growth of crystals, of both spar and ore, in the deserted galleries of old mines, there seems nothing unreasonable in the supposition that whatever may be the geological antiquity of the rocks which enclose mineral veins, or of the fissures and cavities which traverse the rocks, the period during which the spars and ores were deposited in those veins may be much more recent, and very extended; and in many cases that deposition may be even still going on.

* *Quart. Jour. Geol. Soc.*, vol. xxiii. p. 483; and *Brit. Assoc. Rep.* for 1869.

SECTION II.

SURFACE AGENCIES.

CHAPTER XXI.

THE ATMOSPHERE.

THE geological agencies, whose mode of working and effects have now to be considered, are those which act on the surface of the globe. They consist of the atmosphere, of the water which circulates as rain, springs, snow, ice, and rivers between land and sea, of the ocean, and of the agencies of plant and animal life. All these various forces are so intimately blended in their operations that we cannot adequately realise the work performed by any one unless taken in conjunction with the others. Hence no systematic subdivision of them can be other than arbitrary and artificial. For the sake of the convenience of a geological arrangement we may group them as follows:—1. The influence of the atmosphere in destroying rocks and forming new deposits. 2. The conservative, destructive, and reproductive effects of vegetable and animal life. 3. The results of the circulation of water between land and sea. 4. The geological action of the sea.

1. THE ATMOSPHERE.

Though sharp lines of demarcation cannot be drawn between the various ways in which the atmosphere affects the surface of the land, we may yet recognise that, on the one hand, it shows a tendency to disintegrate and remove the superficial parts; and, on the other, to heap up the disintegrated materials into new deposits. In the former operation the action is partly mechanical and partly chemical—in the latter it is almost wholly mechanical. It is to be noted, however, that when we speak of the destructive or reproductive effects of the atmosphere, or of any other geological agent, we do not necessarily imply that anything useful to man is either destroyed or reproduced, still less that anything is destroyed in the sense of annihilation. We shall find, on the contrary, that the destructive effects of the atmosphere help to turn barren rock into rich soil, while its reproductive effects often turn rich land into barren desert. The two terms, therefore, are used in a

strictly geological sense, to denote the removal of material from one place, and its re-deposition in a new form in another.

a. Destructive Effects.

Weathering of Rocks.—Under the name of "weathering" are included the various modes in which the surfaces of rocks exposed to the weather decay. This decay is effected partly by the chemical action of air upon rocks, partly by the loosening influence of great, and especially rapid changes of temperature, partly by the chemical and mechanical effects of rain, and partly by the expansive and disintegrating effects of frost. The action of rain and of frost will be more particularly described in the sequel. The chemical influence of the atmosphere upon rocks consists chiefly in the oxidation of those minerals which can contain more oxygen, as in the peroxidation of protosalts of iron, and in the absorption of carbonic acid by rocks, and the production of carbonates and bicarbonates, which still further aid in the process of decomposition. The mechanical effects of extreme changes of temperature are seen in the way in which different rocks expand and contract. Allusion has already been made to the experiments of Colonel Totten, in America, which were suggested by the impossibility of making tight joints of masonry in a country where the annual range of temperature is more than 90° Fahr.* The alternate expansion and contraction, more especially when it takes place rapidly, tends to disintegrate the surface of the rocks into sand, or to make it crack off in skins or irregular fragments. Dr. Livingstone mentions that in Africa (lat. 12 S., long. 34 E.) he found the rocks which, during the day, were heated up to 137° Fahr., had their surfaces so rapidly cooled by radiation at night, that the contraction was such as to split the stone, and to throw off sharp angular fragments from a few ounces to one or two hundred pounds in weight.†

The manner in which rocks yield to weathering is regulated chiefly by their composition and texture. Of those which are not readily altered chemically, the more porous varieties yield more easily to disintegration than the more compact. Of those which are prone to chemical alteration, such as are rich in carbonate of lime, as common limestone or chalk, are most rapidly wasted. Purely siliceous rocks are those least affected, purely calcareous rocks are those most affected by weathering. The relative hardness of the rocks has no necessary relation to the nature or rapidity of their mode of weathering. Soft clay, where protected from the influences of running water, may resist the action of the weather longer than crystalline limestone, though runnels of water will of course cut a channel in the clay more rapidly than in the limestone. The student who wishes to pursue the subject of the chemical changes, and the nature of the products in the weathering of

* See *ante*, p. 357.

† Livingstone's *Zambesi*, pp. 492, 516.

rocks, should consult such works as those of Bischof, Roth, Senft, etc.* The following illustrations are all that the space of this work will admit of:—

Limestone.—Pure limestone gives rise to little or no soil, and forms therefore bare ridges and hills. The reason of this is, that the carbonic acid absorbed by rain from the atmosphere dissolves the rock and removes it in solution. Those limestones, however, which contain much silica, or silicate of alumina, and some protoxide of iron, diffused through their mass, are converted into the substance known as *rottenstone*, by the action of the weather dissolving and removing the carbonate of lime, leaving the fine-grained rusty siliceous matter. Calcareous sandstones sometimes weather in a similar way, the hard quartz grains projecting from the surface of the rock until eventually washed off, as the calcareous matter is dissolved.

Dolomite.—In some of the bands and veins of dolomite that traverse the Carboniferous limestone of Ireland, the magnesian part falls into a sand of minute crystals which have separated, apparently under the influence of the weather, in consequence of the perfect formation of each crystal, while the imperfect crystals of the adjacent crystalline limestone have remained interlaced and still form a solid marble. The separated crystals of the dolomite do not seem more decomposed than do those of the limestone.

Doleritic Rocks.—These rocks consist essentially of labradorite, augite, and titanoferrite. The felspar weathers by the conversion of its silicate of lime into carbonate, which is removed in solution. The augite has its protosilicate of iron converted, by addition of oxygen from the atmosphere, into persilicate, and its silicate of lime is changed by carbonic acid into carbonate.† Doleritic rocks have consequently a crumbling crust of decomposed and decomposing minerals, which fall down into sand and loam, to form new and usually excellent soil. In some cases, where the disintegration proceeds to a greater depth, the rock can be dug out with the spade, as a brown highly ferruginous sand; in which, however, the characteristic globular internal arrangement of the rock is sometimes very well retained.

Granite.—The extent to which granite and gneiss are sometimes weathered is very wonderful. In many cases hills of granite admit of being dug into by pickaxe and spade, to a depth, in some places, of 20 or 30 feet, the crystals of quartz, felspar, and mica, no longer adhering to each other. That these crystals have not been transported as debris, is proved not only by their angular character and their occupying their natural positions with respect to each other, and there being no signs of arrangement in layers, but also by the occurrence of small branching quartz veins sometimes running through the mass, just as they do through solid granite, showing that it is really a granite decomposed *in situ*. In Devon and Cornwall this decomposed granite is known as "growan."‡

Depth of weathered band no test of the rapidity of weathering of the rock.—It must be particularly borne in mind that the depth of the weathered band round any block of rock is by no means a proof of the ease or rapidity with which it yields to the influence of the weather,

* Bischof's *Chemical Geology* (Cavendish Society's translation) is a storehouse of facts. Roth's prolonged researches from 1861 to 1868 throw light on the weathering of the crystalline rocks, and will be found reprinted from the *Transactions of the Roy. Acad. Sciences of Berlin*, as a separate work, *Beiträge zur Petrographie der Plutonischen Gesteine*, Berlin, 1869. Senft's recent *Lehrbuch der Mineralien und Felsartenkunde* (Jena, 1869) gives some details regarding the weathering of rocks and minerals; and reference may also be made to his *Steinschutt und Erdboden* (1867), and his *Humus, Marsch, Torf, und Limonitbildungen* (1862).

† Bischof, ii. 230.

‡ It is frequently mentioned in different papers, published by the Royal Geological Society of Cornwall. In a paper, in the 4th volume, by Mr. J. Hawkins, soft "growan" is said to ccur in the mine at Carclaze, at a depth of 138 feet from the surface.

but, on the contrary, may be an evidence of the extent to which it resists it. Pure limestones, as has been already remarked, will not exhibit any weathered band, because the carbonic acid of the rain almost at once dissolves and removes the particles it acts upon, so that the more crystalline particles stand out in relief. It is only very impure limestones that yield "rottenstone." Even with igneous rocks the composition may be such that those which weather most rapidly may not show the greatest depth of weathered band beneath the surface, owing to the removal of the particles as soon as disintegrated.

Effects of Wind.—Geological changes are brought about by the mechanical effects of wind. Sand driven by prevalent winds over rocks scratches and polishes them. It is said that at Cape Cod holes have even been drilled in window glass by the same agency.* The influence of wind in raising waves on lakes and on the sea may be referred to here, although wave-action falls to be noticed in a subsequent part of this section. Hurricanes are likewise geological agents upon land, in uprooting trees, and thus sometimes impeding the drainage of a country, and giving rise to the formation of peat-mosses.†

β. Reproductive Effects.

Soil.—Although rocks are disintegrated by the atmosphere, their detritus is not destroyed. Part of it is washed away by rains and streams, but part remains on the land, and gives rise to new soil. All soil is the result of the decomposition of rocks mingled with decayed vegetable and animal matter. If rain did not come into play, and wash the materials of soil to a greater or less distance from their source, the soil of every locality ought to be simply the decayed upper surface of the rocks underneath. But, in proportion to the slope of the ground and the quantity of rain, the soil is moved from higher to lower levels, so that in many cases a good soil comes to lie upon rocks, which of themselves would only produce a poor soil. The action of rain in the formation of soil is referred to in Chapter XXIII.

Sand-hills and Dunes.—Wherever prevailing winds blow upon loose materials, such as sand, they tend to drive them onward, and pile them into irregular heaps and ridges. This takes place characteristically on the windward side of land where the shores are sandy; but it is also to be seen even in the heart of a continent, as in the sandy deserts of the Sahara and of Arabia. Along low sandy coasts, hills are formed of drift sand, which sometimes reach a height of 200 or 300 feet. These hills are commonly called "dunes." They have been described as advancing on the low shores of France, in the Bay of Biscay, at the rate of 60 and 70 feet per annum, overwhelming houses and farms in their progress.‡ The coast of Norfolk

* Dana's *Manual*, p. 631. † See *postea*, p. 383.

‡ This progress has, within the last quarter of a century, been arrested by the planting of pine forests, the turpentine of which has become the source of a large revenue.

is in some places bordered with sand-hills 50 to 60 feet high. Similar accumulations take place on the coast of Cornwall, where the sand, composed largely of fragments of shells and corals, becomes converted sometimes into a hard stone by carbonate of lime or oxide of iron.*

Large areas of blown sand are likewise found along many parts of the Scottish coast line.† Along the south coast of Wexford, as also in Smerwick harbour (county Kerry), similar accumulations are in progress.

"On the eastern coast of Australia," says Mr. Jukes, "about Sandy Cape, this process is going on on a still larger scale. In Port Bowen, in the same neighbourhood, I once saw a very good instance of it. The rise and fall of tide there is as much as sixteen feet; and, at low water, great sandbanks are exposed, derived from the shallow sea outside, and the waste of the porphyritic rocks on the coast. These sandbanks rapidly dry under the hot sun; and the trade-wind, which blows home upon the shore, then drifts the sand up upon the beach, and piles it into hills 50 or 60 feet high. Behind these hills is a large mangrove swamp, which is being gradually buried under the advancing sand, some of the mangrove-trees only just peering above it, others half covered, and so on. The drift of sand through the gaps of these dunes was exactly like a snow-drift in a heavy storm, whenever the wind blew freshly. Large districts, with hills of 200 or 300 feet in height, are found also on the coasts of Western Australia, stretching sometimes ten miles inland, formed of loose incoherent sand, once apparently drifted by the wind, though now brought to rest by the growth of a wide-spread forest of gum-trees. Parts of these sands, which consist greatly of grains of shells and corals, are compacted together into a stone, hard enough to be used for building, by the action of the rain-water dissolving some of the carbonate of lime, and re-depositing it on evaporation. Curious cylindrical stems, from one inch to eighteen inches in diameter, are there seen projecting from the soil, and have been taken for petrified trees, which they greatly resemble; but I observed, in 1842, a number of these supposed trees exposed in a little cove, south of the entrance of Swan River, ending downwards in tapering forms like stalactites; and I believe them, therefore, to have a stalactitic origin, due to the percolation of water down particular pipes and channels in the sand.

"In the interior of great dry continents there are great vast spaces covered with sand and sand-hills, which are shifted and carried about by the wind, just as some sandbanks are deposited now here now there, carried about by the water. We have but to recall to the mind of the reader the well-known stories of caravans crossing the desert, being met and sometimes overwhelmed by moving columns of sand, and the way in which many of the temples of Egypt have been buried under such

* De la Beche's *Manual*. † Geikie's *Scenery of Scotland*, p. 74.

accumulations, for him to see that this action cannot be altogether overlooked. Egypt would probably have been long ago obliterated by drift-sand, if it had not been for the Nile, and the strip of vegetation that accompanies and defends it." * Mr. Palgrave has given a graphic narrative of the great sandy deserts and hills of Arabia, while Captain Sturt reports the existence of vast deserts of sand in the interior of Australia, with long lines of great sand-hills, 200 feet high, the base of one touching that of its neighbours, and all stretching in straight lines each way to the horizon.

Dust-showers, Blood-rain.—In hot countries, subject to great droughts and to violent hurricanes, the dust and sand of dried lakes and river-beds is sometimes swept up into the upper regions of the atmosphere, where, encountering some strong aërial current, these fine transported materials are carried for hundreds and even thousands of miles, and descend again to the surface, in far-distant regions, in the form of "red-fog," "sea-dust," "sirocco-dust," or blood-rain." This far-carried dust is of a brick-dust or cinnamon colour, and is sometimes so abundant as to darken the air and hide the sun, and to cover with a thick coating the sails and rigging of vessels which may even be hundreds of miles from land.† If the dust encounters rain, it mixes with it, and falls either on sea or land as what is popularly called "blood-rain." It is common on the north-west of Africa, about the Cape de Verd Islands, also in the Mediterranean and its bordering countries. A microscopic examination of this dust, by Ehrenberg, has shown that it is largely made up of diatoms of South American species, and he infers that a dust-cloud must be "constantly swimming in the atmosphere, by means of continuous currents of air, and lying in the region of the trade-winds, but suffering partial and periodical deviations." It is easy to see that a prolonged continuance of this action must give rise to wide-spread deposits of dust, mingled with the soil of the land, and with the silt and sand of lakes, rivers, and the sea; and that the minuter organisms of tropical regions may thus come to be preserved in the same formations with the terrestrial or marine organisms of temperate latitudes.‡

Transportation of Seeds.—The same cause by which dust and minute animal or vegetable organisms are carried to a distance of many thousand miles through the air, may come into play also in the transport of living seeds, which, if they finally reach a congenial climate and soil, may take root and propagate. We are yet, however, very ignorant as to what extent this cause has actually operated in the establishment of any given local flora.

* Jukes, in last edition of this Manual. † Maury, *Physical Geography of the Sea*, p. 145.
‡ See Humboldt's account of the dust whirlwinds of the Orinoco, in his *Aspects of Nature*; also Maury, *Op. cit.* chap. vi.; and Ehrenberg's work, *Passat-Staub und Blut-Regen*. 1847.

CHAPTER XXII.

GEOLOGICAL ACTION OF PLANT AND ANIMAL LIFE.

Apart from their own interest in relation to the history and distribution of life upon the globe, plants and animals may be regarded as geological agents, producing by their growth and decay certain not unimportant geological results. We may consider these results briefly, under the heads of Destructive, Conservative, and Reproductive Action.

α. Destructive Action.

Plants bring about the destruction of rocks and soils in several ways—1st, Their roots exert a direct mechanical force when they insert themselves into the joints and crevices of rocks, and cause fragments, sometimes of considerable size, to be detached. We see the same action at work when a tree, which has found footing in the wall of an old building, sends its roots through rifts of the ruin and loosens large irregular pieces of the masonry. 2d, Plants, such as mosses and liverworts, keep the rocks moist on which they grow, and enable water to lodge upon their rock-surfaces and rot them. 3d, The decay of plants of all kinds gives rise to the formation of carbonic acid, part of which, being absorbed by rain-water, is carried down through the soil, and is one of the great agents in effecting the decay and chemical changes of rocks. 4th, Thick woods and deep mosses are said to attract rain, and if so, they indirectly tend to increase the amount of denudation in a country.

Animals exercise a less markedly destructive action upon the surface of the earth. The most familiar examples of this action are furnished to us by the smooth long cylindrical holes made in shore rocks by the boring-shells, and in the timber of wooden piers or ships by the teredo. Local changes are sometimes brought about where the course of a stream, or the drainage of a district, is affected by the constructions of the beaver, or the burrowing habits of the rabbit, mole, etc.

β. Conservative Action.

Plants help to preserve the surface of the land—1st, By the formation of a stratum of turf, which prevents loose soil from being

rapidly washed away by rains, rivulets, and rivers, and keeps rocks from being so exposed to weathering as they would otherwise be.* 2d, By binding loose materials with roots, rootlets, and fibres, as is done by the *carices* upon loose sandhills, and by the roots of shrubs and trees along the margin of a watercourse. 3d, By opposing resistance to the destructive action of floods and avalanches. This is done by forests and thickly-matted underwood, whereby the loose materials, mud, leaves, etc., swept down by inundations, are caught and retained, and made to increase the depth of soil and to resist the encroachments of subsequent floods; also, by the same agency, masses of descending snow are arrested and kept from descending into and destroying the cultivated valleys below. Most visitors to Switzerland will remember, among others, the Bannwald of Altorf, which is carefully guarded as a protection from the falls of snow and rock from the overhanging mountains.

Animals do not exert any material conservative action upon the surface of the earth, except in so far as they form new deposits—an action, however, which falls to be described in the following paragraphs.

γ. Reproductive Action.

Not only do plants and animals help in various ways both to disintegrate and to preserve the present surface of the earth, they form, by the accumulation of their remains, new deposits of great geological importance. This action has also been in progress from the earliest geological times, and has given rise to almost all the limestone formations of the globe, as well as to others of much interest and value in geological history. To trace the geographical distribution of plants and animals, their relation to climate, and the conditions which are favourable or not to their development, belongs to natural history rather than to geology. But some remarks will be offered on these questions in the part of this Manual which treats of palæontology. In the meantime we are concerned only with the mode in which plants and animals make new formations over the surface of the globe.

Plant Formations.—In temperate and arctic climates certain plants (*sphagnum, etc.*), form in moist hollows and level spaces wide and deep accumulations of their remains, to which the name of peat-mosses or bogs is applied. The roots of these plants decay, while the upper surface continues to grow; and in this way deposits of peat, 10, 20, or even 40 feet in thickness are formed. The peat is loose and fibrous at the top, but becomes firmer further down, till at the bottom of a

* See Elie de Beaumont's *Leçons de Géologie Pratique*, 1843, tome i. p. 135 *et seq.* The conservative effects of turf are much exaggerated by many writers, as, for example, by M. de Beaumont in the work just cited. His arguments are given in Chapter XXV. of this Manual.

deep moss it is sometimes so compact as to resemble brown lignite. There are some large mosses in the British Islands; and they are said to cover about a tenth of the surface of Ireland. They are extensively developed also in some parts of France, in the United States, and in Canada.

Some of the British mosses are believed to have been formed by the extensive destruction of forests by human agency, from the time of the Romans downwards. Others have arisen from the destruction of forests by storms. In such cases, the marsh plants spring up, owing to the way in which the prostrated trees interrupt the drainage of the country, and the trunks are gradually enveloped in and buried under a growth of peat. Many peat-mosses have evidently at one time been lakes, the water having been gradually displaced by the growth of vegetable matter.

Men and animals are often lost in soft swampy peat-bogs. The peat has an antiseptic property, whereby the flesh, skin, and hair, as well as the bones of animals, are preserved, or sometimes in part converted into adipocere.*

The mangrove swamps of tropical countries are another instance of the gradual displacement of water and increase of land by the growth and decay of vegetables. These swamps perhaps furnish the nearest parallel at present existing to the way in which coal was formed. Chemical analysis shows that a gradation can be traced from the composition of ordinary wood through peat and lignite to the most mineralised forms of coal.

The following Table contains the mean composition of wood, the mean of three analyses of peat, of four sets of analyses of lignite, comprising twenty specimens, of sixty-seven analyses of coal, and the extreme of several analyses of different kinds of anthracite.†

COMPOSITION OF CARBONACEOUS SUBSTANCES.

	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Earthy Substances or Ash. Min. Max.
Wood .	49·1	6·3	44·6	— —
Peat . .	54·1	5·6	40·1	4·6 to 10·0
Lignite .	69·3	6·6	25·3	0·8 to 47·2
Coal . .	82·1	5·5	12·4	0·24 to 35·5
Anthracite .	95·0	3·92	3·45	0·94 to 7·07

* For accounts of peat and mosses, see Rennie's *Essays on Peat*, 1810; Steele's *Peat-moss or Turf-bog*, 1826; Geikie's *Scenery of Scotland*, p. 327; Mr. James Geikie "On Peat," *Trans. Roy. Soc. Edin.* vol. xxiv. p. 363.

† Bischof, *Op. cit.* vol. i. chap. xv.

Animal Formations.—The softer parts of animal organisms almost always decay, and are resolved into water, ammonia, carbonic acid, etc. The harder parts, however, often accumulate and form extensive deposits. On land which lies in a rainless or nearly rainless tract, the droppings of sea-birds gather into thick beds of what is known as *guano*. In fresh water the remains of molluscs and calcareous algæ form deposits of fine white calcareous mud called *marl*, which, on dried lake-bottoms, is often dug for agricultural purposes.

"The beds of the lakes in the limestone districts of Ireland have often a thick deposit of white mud, which, when dry, is almost like flour in appearance, and is wholly soluble in acids. It is full of undecomposed fresh-water shells of ordinary living species, but does not itself disclose any trace of an organic origin. My friend, Dr. J. Barker, of Dublin, subjected some of it, at my request, to a careful microscopical examination, but could discover no trace of organic structure. Around lakes that have been partially drained, large deposits of this substance, several feet in thickness, may be seen; and, in sounding some of the lakes, I usually found the lead sank into and came up partially coated with this substance.

"In some parts of the shores of the lakes there are accumulations of small nodular concretionary-looking balls of about half-an-inch in diameter, which Dr. Allman, of Edinburgh, told me were a species of nullipore. It is only in the lakes in limestone districts that this deposit is conspicuous."*

In the sea animal remains form much more important deposits than on land or in fresh water. The accumulation of shells and corallines gives rise to the formation of shell-limestone. The droppings of fish, and the shells of lingulæ, and some other molluscs, form phosphatic nodules.† Calcareous foraminifera exist in such numbers on some parts of the ocean-floor as to form there enormous deposits of a chalky mud, which closely resembles chalk in character and origin, and which, according to Professor Wyville Thomson, may really have been formed continuously ever since the cretaceous period by the lineal descendants of the organisms which formed the chalk. Siliceous diatoms, along with the spiculæ of sponges, furnish the materials for siliceous layers and nodules, like the flints of the chalk. Lastly, enormous masses of limestone are formed along the margins of islands and continents, and over submerged land, by the coral-polyps. The following details‡ may be of interest to the student :—

Siliceous Deposits.—To account for the deposition of silica on the bed of the sea, where evaporation is not possible, we are compelled, as in the case of limestone, to call in the aid of the powers of animal life. The minute shells of many of the Foraminifera, as, for instance, the *Polycystinæ*, are composed of silica, which they have extracted from the water of the sea.§ Some kinds of rock, such as Tripoli, or polishing slate, are entirely made up of these microscopic

* MS. by Mr. Jukes. † See *ante*, p. 313, *note*. ‡ By Mr. Jukes.

§ There is a sandstone in Barbadoes which prevails through an extensive district in that island, which is composed of the siliceous skeletons of *Polycystinæ*, more or less firmly united by a calcareous cement (Carpenter's *Foraminifera, Roy. Soc.* p. 21).

substances, some beds thus formed being many fathoms in thickness and many miles in extent. All seas, from the equator to the poles, abound with these minute organisms. They have been found living even in ice. The phosphorescence of the sea is due to the presence of organic beings, a large proportion of which are siliceous-cased infusoria, whether belonging to the animal or vegetable kingdom. According to Ehrenberg, there are formed annually in the mud deposited in the harbour of Wismar, in the Baltic, 17,946 cubic feet of siliceous organisms. Although it takes a hundred millions of these animalcules * to weigh a grain, Ehrenberg collected a pound weight of them in an hour. So prolific are they, moreover, that "a single one of these animalcules can increase to such an extent during one month, that its entire descendants can form a bed of silica 25 square miles in extent, and 1¾ foot thick." As a parallel to Archimedes, who declared he could move the earth if he had a lever long enough, we may say :—"Give us a mailed animalcule, and with it we will separate all the carbonate of lime and silica from the ocean." The silica thus rendered solid may either be deposited alone, or may be mingled with the calcareous matter deposited on the bed of the sea. If the siliceous be diffused in a fine state of division pretty equally through the calcareous matter, it may perhaps be consolidated in that state of diffusion, producing a siliceous limestone, or it may, in obedience to certain chemical laws, segregate itself, more or less completely, from the calcareous matter, and form either distinct layers and veins, or concretionary balls and nodules. The presence of a body, itself consisting largely of silica, such as many sponges, will facilitate and determine this process, affording a centre of attraction for the siliceous particles to collect around it from the adjacent matter.

The small proportion which the siliceous-cased animalcules bear to those that secrete calcareous matter, explains the fact that the siliceous rocks, to which we must attribute an organic origin, rarely occur in large continuous masses, but are usually dispersed in nodular concretions, or thin layers, through the mass of the calcareous or other rocks.

Calcareous Deposits.—The shells of Molluscous animals consist chiefly of carbonate of lime, so do the crusts of the Crustacea and Echinodermata, and as we descend still lower to the Polyps and Foraminifera we meet with animals that secrete still larger quantities of that substance, not only larger in proportion to their own bodies, but much larger absolute bulks of it, in consequence of their numbers. Although the quantity of carbonic acid gas in the sea is so great as to keep fluid all the lime which is already dissolved in it, and even a good deal more than sufficient for that purpose, yet it does not immediately exercise its solvent powers on the carbonate of lime that has been secreted by the organs of animals, since the organic structure seems to protect it, for a time at least, from the merely chemical action of the acid. Moreover, the concentration of so large a proportionate mass of carbonate of lime in comparatively small spaces, would require a long-continued action of currents of sea-water upon it, in order to re-dissolve it, since no portion of water could remove more than one-tenth per cent of its own bulk. †

In the extra-tropical seas, it would seem probable that Foraminifera and other allied animals are the most active agents in the secretion of carbonate of lime. In the series of sounding operations conducted across the Atlantic by the officers of the British and United States navies, preliminary to laying down the electric telegraph, it was found that large parts of the bed of the Atlantic were covered with a calcareous "oaze." Between the 15th and 45th degrees of west longitude lies the deepest part of the ocean between Ireland and Newfoundland, varying

* In using the terms "animalcules" and "infusoria," it must be borne in mind that biologists now believe many of them, such as the Diatomaceæ, to be vegetables.

† Bischof, vol. iii. p. 171.

from about 1500 to 2400 fathoms, the bottom of which is almost wholly composed of a kind of soft mealy substance, which has been called oaze. This substance is remarkably sticky, having been found to adhere to the sounding rod and line through its passage from the bottom to the surface, in some instances from a depth of more than 2000 fathoms. The space indicated equals a distance of more than 1300 miles, in which all the dredgings except two indicated the same kind of bottom.*

Professor Huxley gives a description of the oaze derived from depths between 1700 and 2400 fathoms (or 10,200 and 14,400 feet). He says, "A singular uniformity of character pervades these soundings. As they lie undisturbed they form an excessively fine light brown muddy sediment at the bottom of the bottles in which they are preserved; but in this mud a certain slight grittiness can be detected, arising from the intermixture of minute hard particles (hardly ever exceeding 1-50th of an inch in diameter). . . . When a little of this mud is taken out and thoroughly dried, it becomes white or reddish-white, and (though less white) closely resembles very fine chalk, and fully nine-tenths, as I imagine, by weight of this deposit consists of minute animal organisms called Foraminifera, provided with thick skeletons composed of carbonate of lime. Hence, when a dilute acid is added to the mud, a violent effervescence takes place, and the greater part of its bulk disappears." Professor Huxley believes that 85 per cent of the whole belong to one species of the genus Globigerina, 5 per cent to other calcareous organisms of at most four or five species, and the remaining 10 per cent consists partly of minute granules of quartz, and partly of animal and vegetable (diatomaceæ) organisms provided with siliceous skeletons and envelopes.†

It will be seen, therefore, that the materials for a continuous bed of limestone with flint nodules are now being deposited in the North Atlantic over a space which is 1300 miles in diameter, a distance equal to that from the west coast of Ireland to the borders of Russia, or from Paris to Constantinople. In the second pamphlet by Captain Dayman, published in 1859, describing the line of soundings taken to the Azores in 1858, he states that he found precisely similar oaze nearly down to latitude 45°, so that the deposit appears to be at least 600 miles broad.

Coral Reefs.—The solidification of carbonate of lime by the forces of life thus discovered to be going on in the depths of the North Atlantic, is doubtless equally active in the other oceans, both within and without the tropics. In many parts of the intertropical regions of the world, however, especially in the Indian and Pacific Oceans, another class of animals, namely, the Actinozoa, produce still greater effects. These are merely soft gelatinous animals, consisting of little else than a small sac or stomach, with tentacles arranged round its margin to assist in supplying it with food. The Actinia or Sea Anemone is a well-known example of these animals. Some kinds of them form a common body, by the union of a great number of individuals, just as a number of individual buds exist in, or grow out of, a common vegetable body or tree; the compound body in each case increasing

* Captain Dayman's *Deep Sea Dredgings* (1858). He says that this is "the greatest dip" or steepest inclination "in the whole North Atlantic Ocean." The numbers indicate an "incline" of 1200 fathoms, or 2400 yards, in 18' of longitude, which in latitude 52° may be taken as very nearly equal to 24,000 yards. This gives an inclination of 1 in 10, or about 6°, a slope which is exceeded by that of many of our carriage roads on dry land. The bed of the North Atlantic has more recently been examined in much greater detail by Dr. Carpenter, Professor Wyville Thomson, and Mr. Gwyn Jeffreys. See *postea*, Part III., Palæontology.

† In parts of the tropical seas much larger species of Foraminifera exist in great abundance, as the author used frequently to bring up, when dredging off the N.E. coast of Australia, bagful after bagful of orbitolites (see Carpenter's *Foraminifera, Royal Society*, p. 105, etc.); and the sands of the neighbouring coasts were often full of these bodies.

in consequence of the multiplication and growth of the individuals belonging to it. Almost all these compound Actinozoa or Polyps, as they used to be called, secrete carbonate of lime, forming a solid compound skeleton or frame-work, called Coral.

In most tropical seas encrusting patches or banks of living coral are to be found along the shores, wherever they consist of hard rock, and the water is quite clear. These Mr. Darwin calls Fringing reefs.

If the slope of the shore be steep, these Fringing reefs are of insignificant extent, since the animals that form them do not flourish at greater depths than about fifteen fathoms, and the largest and most massive kinds seem to prefer the play of moving water, or even the dash and roll of the breakers to more tranquil depths. Where the nature and slope of the bottom is favourable, a Fringing reef may extend a mile or two from the shore, and the whole sea become choked with coral as far out as the original fifteen-fathom line. Dr. Dana says they do not live in water that ever sinks below 66° F., which may be one reason for their limit of depth, and also a reason for their absence from certain intertropical coasts, such as that of South America, which is swept by Antarctic currents of cold water, so that the temperature of the sea sinks sometimes to 58° at the Galapagos. *

In the Indian and Pacific Oceans, far away from any land, huge masses of coral rock rise up from vast and often unknown depths just to the level of low-water. These masses are often unbroken for many miles in length and breadth; and groups of such masses, separated by small intervals of deep water, occur over spaces sometimes of 400 or 500 miles long, by 50 or 60 in width. These often form large irregular rings or loops, and when they do not enclose any high land they are called Atolls.

When the reefs encircle or front high land, with a navigable water-channel between the land and their outer edge, they are called Barrier reefs by Darwin. The Barrier reef along the north-east coast of Australia is composed of a chain of such masses, and is about 1250 statute miles long, from 10 to 90 miles in width, and rises at its seaward edge from depths which in some places certainly exceed 1800 feet.† It may be likened to a great submarine wall or terrace fronting the whole north-east coast of Australia, resting at each end on shallow water, but rising from very great depths about the centre, its upper surface forming a plateau, varying from 10 to 30 fathoms in depth, which is studded all over with steep-sided block-like masses that rise up to the level of low water. These masses vary in size from mere pinnacles to an area of ten miles in length, by one or two in breadth, the length running more or less nearly across the direction of the prevailing wind. They are especially numerous and most linear along the edge of the great bank on which they rest, the passages between them being sometimes two or three miles wide, but often very narrow, like irregular embrasures opened here and there through the parapet wall of a fortress. These "individual reefs" running along the outer edge protect the comparatively shallow water inside, and, with the numerous inner reefs that are scattered over its space, make it one great natural harbour. An idea of its extent may be gained by supposing it transferred to our own part of the world, where it would extend from Brest across the mouths of the English Channel and Irish Sea, round the west coast of Ireland to the extreme west point of Iceland, or curve along the shores of Scotland and the Shetland Islands up to the coast of Norway.

In the deep sea around, and in all the neighbouring seas, from Torres Straits to the Straits of Malacca, wherever "bottom" is brought up by the lead, it is found to be a very fine, almost impalpable, pale olive-green mud, which is wholly soluble in dilute hydrochloric acid. This substance, when dried, would therefore be scarcely different from chalk, though it commonly is of a greener tinge. This

* Dana's *Coral Reefs*, p. 99. † See *Voyage of H.M.S. Fly*, vol. i., chapter 13.

fine calcareous mud may be partly derived, like the oaze of the North Atlantic, from the calcareous bodies of minute animals; but much of it is doubtless produced from the waste of the coral reefs themselves. Some fishes, according to Mr. Darwin, browse upon living coral, and all the great Holothuria (or Tripang), so abundant on the coral reefs of the Great Barrier and elsewhere, are always full of coral sand.* The mere process of digestion, then, carried on by these and other animals, must contribute much impalpable calcareous mud to the adjacent seas.

The tidal currents among the "inner reefs," and in the openings of the Great Barrier, are often excessively strong, running sometimes with an impetuous sweep, in the same direction, even for two or three days together, especially after great storms have driven large quantities of water into the space between the outer edge and the land.† The outer edge of the Great Barrier (and the windward side of all coral reefs) is always subject to the battering and pounding action of the most tremendous surf that can be imagined, since the long roll of the ocean-swell falls suddenly on the upper edge of the great submarine wall, dashing upon it with almost inconceivable power, and roaring over the surface of the reef in huge breakers, that are sometimes felt even all across it. At high tide especially, when the wind blows strongly on the reef, a vast quantity of water is thus thrown into the inner lagoon, which, as the tide falls, scours out all the outer channels and passages. Although the living coral flourishes most where the surf is heaviest, and the greatest masses of Mæandrina and Porites,‡ and other gigantic species, live only on the outer edge of the reef; yet if a mass, living or dead, be once detached from the rest, it is soon acted upon by these breakers, and ultimately triturated into calcareous sand or mud.

In addition to the Great Barrier just spoken of, all the sea between Australia, New Caledonia, and the Louisiade, is infested with coral reefs, so that Flinders called it the Coral Sea. As this space is 1000 miles wide and broad, we have here an area of something like a million of square miles over which carbonate of lime has been consolidated into great sheets and bank-like masses, which are in some parts at least more than 1000, probably more than 2000, feet in thickness.

Consolidation of the Materials of Coral Reefs.—Those coral reefs which may be called living reefs, consist of living corals only in parts of their upper surface, and along their outside rim, the living part being a mere film compared with their whole bulk. All the interior is composed of dead corals and shells, compacted together by calcareous sand and mud, derived from the waste of other corals and shells, and by countless myriads of minute calcareous organisms. The living part, even of the upper surface of the reef, is that only which is never dry at low water. The part which is then exposed is composed of mere stone, often capable of being lifted in slabs, bearing no small resemblance to some of our oldest limestones. These slabs and blocks, when broken open, are frequently found to have a crystalline structure internally, by which the organic structure of the corals and shells is more or less disguised. A coral reef, then, of which a part is still living and in process of formation above, may internally consist of solid crystalline limestone.

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* Darwin, *Coral Reefs*, p. 14. † *Voyage of H.M.S. Fly*, vol. i., p. 19.

‡ Rounded masses, or solid stools of Mæandrina, of 6 or 8 feet in diameter, are common among the detached blocks rolled up from the outer slope on to the reef. They may be seen just inside the surf, at low water, from a distance of one to two miles, and are spoken of by Flinders as "Turks' Heads." I once landed close to the edge of the Barrier, on the south side of the Blackwood Channel, in south latitude 11° 45′, on a continuous mass of Porites, which was at least 20 feet across, and seemed to pass downwards into the mass of the reef below water without any disconnection. It was worn into pinnacles above, so that two or three of us could stand in the different hollows without seeing each other. This formed part of a line of such masses that attracted our attention from a distance of three miles. They are marked as "rocks dry at *high* water" in the charts.

On the upper surfaces of some coral reefs small sandy islands are formed,—the coral sand being drifted by the winds and waves till it forms a bank reaching above high-water mark. In some of these islands, the rounded calcareous grains are bound together into a solid stone by the action of rain water, which dissolves some of the carbonate of lime as it falls, but, being shortly evaporated, re-deposits it again in the form of a calcareous cement. The stone thus formed is like a cake resting upon still incoherent sand below. Some of this stone, which was used for building a beacon tower on Raines' Islet, to mark an opening in the Great Barrier reef, presented very distinct examples of the oolitic texture, little minute grains and particles being enveloped in one or two concentric coats, like the coats of an onion. That this stone was not consolidated under water is proved by nests of turtles' eggs being found imbedded in it, evidently deposited by the animal when the sand was above water, and was still loose and incoherent.

Raised coral reefs, in the islands of Timor and Java, are internally almost as white and friable as chalk, though they have frequently a rougher and grittier texture, and weather black outside. The weathered surfaces of these limestones, often at a height of two or three hundred feet above the sea, with their embedded shells of all descriptions, including a Tridacna of one or two feet in diameter, differ in no respect from some of the surfaces of the Great Barrier reef, where exposed at low water,* though no one who is not familiar with coral reefs would suppose them to have had such an origin. Dr. Dana insists strongly on "the perfect compactness and freedom from fossils of a large portion of the coral rock, although made within a few hundred feet of living corals and shells;" and also mentions the "oolitic structure of part of this compact kind."† He speaks of one kind of coral rock as "a fine-grained, compact, and clinking limestone, as solid and flint-like in fracture as any Silurian limestone, and with rarely a shell or fragment of coral."‡ I can corroborate these observations, as nothing struck me more when walking on coral reefs than the great resemblance of the slabs lying about to those on the surface of the limestone quarries near Dudley.§

Guided by these facts and observations, we may form tolerably accurate notions of the mode of origin of all our marine limestones, and attribute to them an organic-chemical origin, taking into account, at the same time, how easily they may have been subsequently altered in structure or texture by the metamorphic action either of water or of heat. We must also bear in mind that although the carbonate of lime may have been secreted and brought into a solid form from its aqueous solution by the action of animal life, yet that the original form it thus received has been retained in only a small part of it, the great mass having been subjected to the mechanical actions of erosion, trituration, and transport, to a greater or lesser extent, in the process of its conversion into calcareous mud, and deposition as beds of limestone, as well as to the metamorphic action of carbonated water.

Summary.—Plants living on the land extract carbon from the air and mineral substances from the soil, and, under favourable circumstances, their remains gather into new formations as turf and peat.

Animals assimilate into their own bodies the organised substance of plants, and in the lower grades of the animal kingdom secrete large masses of carbonate of lime, silica, and other mineral compounds from

* *Voyage of H.M.S. Fly.* † Dana's *Manual*, p. 624. ‡ *Ib.*, p. 617.

§ It must not be supposed that the thin and comparatively insignificant calcareous bands in the Silurian rocks ever deserved the name of coral reefs, or that even the carboniferous limestone was chiefly derived from corals. The animals that are now the main producers of limestone in some parts of the world are those which form corals,—the animals that were the main producers of limestone in some parts of the world in the carboniferous period were the crinoids or sea-lilies.

the inorganic world. To a small extent upon land and in fresh water, but on a great scale upon the floor of the ocean, the skeletons, shells, and other exuviæ of animals gather into vast formations of stratified rock.

Mineral matter is thus, after being subject to the destructive agency of mechanical force, and after apparently disappearing under that of chemical action, brought back to the solid form by the power of life, and having served the purposes of organic beings is delivered over again, as dead matter, to perform the same round of service at some future and perhaps far distant period. We build our houses by aid of materials derived from animals that perished thousands of ages ago, and we warm and light them from those of equally long perished plants, restoring to the atmosphere the carbon that originally floated in it, and giving back to the dust, and then to the waters of the earth, the lime that was formerly dissolved in them.

CHAPTER XXIII.

CIRCULATION OF WATER UPON THE LAND.

APART from the action of the underground forces, already considered, water is the great agent by which the surface of the globe is altered. There is a ceaseless circulation of water between land and sea, sea and land; and by means of this circulation the solid land is worn away, valleys are excavated, and the debris is carried out into the ocean, there to be accumulated into fresh strata, which shall eventually be raised into new land. The vapour raised by solar heat from the earth's surface rises into the atmosphere, condenses there into clouds, and falls again to the earth as rain, snow, or hail. That portion which reaches the land partly flows off again into the sea by streams, partly sinks underground, and, after performing there a subterranean circulation, rises once more in the form of springs, and returns to the ocean. The water which is raised by evaporation falls nearly pure upon the land; but when it returns again to the sea it is no longer pure, but charged with mineral matter in chemical solution and mechanical suspension. As this circulation is constantly going on, and as the water which flows off the land is constantly and everywhere carrying the detritus of the land into the sea, it is evident that we have here a system of geological change of the most stupendous character.*

That the notice to be here given of this system may be as clear and succinct as possible, we shall arrange the subject as follows:—1st, The fall of water upon the land as rain; 2d, The course of that part of the rainfall which sinks underground and re-appears in the form of springs; 3d, The work performed by that part of the rainfall which flows off in streams into the sea; 4th, The action of frozen water,—frost, snow, river-ice, and glaciers.

* The geological importance of the circulation of water over the surface of the land was first realised and insisted on by the great Hutton, in his Theory of the Earth (*Trans. Roy. Soc. Edin.*, vol. i., p. 209, 1785, afterwards expanded and published in 1795 as a separate work). Notwithstanding the eloquent elucidations of his friend Playfair, Hutton's doctrines on this subject lay dormant for half-a-century. It is only recently that they have been revived and adopted by a growing body of geologists, consisting largely of the younger men, and of those who are engaged professionally in the daily survey of rocks and rock-features. The student will find the literature of this subject, up to 1867, referred to by Mr. Whitaker, *Geol. Mag.*, vol. iv., p. 447. Since that time, however, additional memoirs have been published, to some of which reference will be made in the course of the following discussion.

1. Rain.

Rain acts upon the surface of the earth in two ways,—1st, Chemically; and 2d, Mechanically.

1. The Chemical Action of rain arises chiefly from the solvent power of the carbonic acid which the rain absorbs from the atmosphere, and which acts upon rocks containing carbonates and silicates; partly, also, from the way in which its oxygen combines with substances not yet fully oxydised. Rain, therefore, removes certain ingredients of rocks in chemical solution, and helps by chemical changes to disintegrate rocks.

2. The Mechanical Action of rain is shown by the way in which it washes off the finer particles of disintegrated rock or of soil, and carries them down to lower ground, or into streams. The fine detritus is either held in mechanical suspension in the rain-water, or merely pushed along the surface.

Results of Rain-Action.—The importance of rain as a geological agent can only be adequately realised when the general denudation of a large district is studied. In every country in which rain falls the whole surface is exposed to this action. Hence, as Hutton first pointed out, the superficial covering of disintegrated rock or soil is constantly travelling, slowly, indeed, but certainly, outward and downward to the sea. This wasting of the surface is not entirely the work of rain. We have seen that the atmosphere helps, and additional aid is given in many countries by the action of frost. Rain, however, is the agent by which the work of the other forces is made conducive to the general degradation of a land-surface; for it is by rain that the layer of disintegrated rock, which would otherwise accumulate over the solid rock and protect it from further decay, is removed, and a fresh surface of rock is exposed to further disintegration. This decay of a land-surface, though general and constant, is not uniform. There are some places where, from the nature of the rock, from the flatness of the ground, or from other causes, rain works under great difficulties, and where, therefore, the rate of waste must be inconceivably slow. There are other places, again, where the rate is so rapid as to be readily appreciable from year to year. It will be pointed out, in a subsequent chapter, that this inequality in the rate of waste has been largely instrumental in bringing about the present relief of the land, those parts where the waste is greatest forming hollows and valleys, while the others, where it has been less, form table-lands, hills, and mountains.

The general decay of the surface of the land has enabled rain to collect in favourable situations considerable accumulations of loam and earth—the washings from adjoining higher ground. Of such a nature are the "*brick-earth*," "*head*," and "*rain-wash*" of the south of England

—earthy deposits, sometimes full of angular stones, derived from the subaërial waste of the rocks of the neighbourhood.* In some parts of the Alps thick deposits of earth, formed by old glaciers, and abounding in large stones, have been cut by the vertical fall of rain into pillars—the formation of which is explained by the fact that each pillar is capped with a stone, which has protected the earth underneath it while the surrounding portions were being cut away.†

2. Underground Water.

When rain falls upon land, part of it, instead of running off in brooks and rivers, sinks underground, and, after a more or less circuitous journey there, returns to the surface in the form of springs. The geological changes effected by underground water are twofold—1st, Chemical; 2d, Mechanical.

1. The **Chemical Action** of undergound water depends either upon the solvent power of its carbonic acid, or upon the influence of internal heat. In the one case we have the cause of the changes carried on by ordinary springs; in the other, the cause of the action of very deep-seated and thermal springs.

Rain-water and snow contain small quantities of carbonic acid derived from the atmosphere, and acquire more in sinking through the soil. If water, in circulating underground, meets with carbonic acid gas rising from the interior, it becomes saturated with it, and carbonated springs are produced. The waters of springs, rivers, and lakes, therefore, always contain some, and probably a very variable amount of, carbonic acid gas. Carbonate of lime is nearly insoluble in pure water, but if the water contains sufficient carbonic acid, the mineral is easily dissolved by it, in consequence of the carbonate being converted into a soluble salt, in the form of a bicarbonate or sesquicarbonate of lime. The quantity of carbonate of lime held in solution by water containing free carbonic acid is likewise very variable. In springs it may occasionally reach the point of saturation, which is about 105 parts in the hundred thousand.

When water containing carbonate of lime in solution suffers from evaporation, each drop of water loses both water and carbonic acid gas, thus becoming gradually saturated with the carbonate of lime without gaining any increase in solvent power.‡ When, then, the evaporation is continued beyond the point of saturation,

* See Austen, *Quart. Journ. Geol. Soc.*, vi. 94, vii. 121; Foster and Topley, *Quart. Journ. Geol. Soc.*, xxi. p. 446.

† See Lyell's *Principles*, vol. i. p. 335.

‡ Bischof (vol. iii. p. 171) says that the maximum amount of carbonate of lime that can be dissolved in water, saturated with carbonic acid, is 0·1 per cent, but that water containing only one-tenth as much carbonic acid as a saturated solution, would dissolve just as much carbonate of lime as a saturated solution would, even if it were under high pressure. The existence of carbonated springs, therefore, is not at all necessary for the deposition either of stalactites, travertine, or calc-spar in veins, since ordinary meteoric water will

some of the dissolved carbonate of lime must necessarily be deposited in a solid form on the substance over which the water passes. Drops of such water, hanging from the roof of a cavern, may be observed to be coated over with a delicate film of minutely crystalline carbonate of lime, like the finest tissue paper. This gradually forms a little tube, which may be seen sometimes to acquire a length of some inches, still retaining all its fragility, until water, trickling down the outside of it, strengthens it by the addition of successive external coats. Water, then, dripping from the roofs of limestone caverns, will form long icicle-like pendants, which grow downward, as well as columns rising from the floor, wherever the water continues to drop long enough on one particular spot. Vertical sheets of this incrustation may even be formed when the water oozes from a long joint or crevice in the roof. The part hanging from the roof is called *stalactite;* that on the floor *stalagmite.* Stalactites, even when some feet long, and several inches in diameter, are often found with the little original central tube still open, since water may pass down it, with little or no evaporation. The limestone thus formed is commonly white or pale yellow, sub-crystalline, often fibrous, and, when thin, semi-transparent or translucent. Some stalactites, while they retain their concentric rings, showing the way in which they were formed, coat over coat, are nevertheless perfectly crystalline internally, the crystals radiating from the centre, and passing through many concentric coats of the stalactite. Stalactites may often be seen under the arches of bridges, vaults, or aqueducts, especially if the stone of which they are built be limestone. Sometimes they are even derived from the carbonate of lime contained in the mortar or cement used in their construction.

Travertine, or *calcareous tufa*, is deposited, by exactly the same process, on the margins of springs, or on the banks of rivers, and the sides of waterfalls. Sticks and twigs hanging over brooks often become coated with it; and the incrustation of birds' nests, wigs, medallions, and other matters, by the action of what are called petrifying wells, is commonly known. In Italy, large masses of solid and beautiful travertine are deposited by some of the springs, so that it is used as a building stone. Bischof says that there are fifty springs near Carlsbad giving out 800,000 cubic feet of water in twenty-four hours, from which, according to Walchner's calculation, a mass of stone, weighing 200,000 pounds, could be deposited in that time. Pipes to convey water, especially water from boilers, frequently become choked up by the deposition of limestone, and have to be renewed. In some manufactories, the deposition inside a pipe exhibits a regular alternation of one white layer between six dirty ones, and this white one is called the "Sunday streak," as marking the deposition on the day when no work was going on, and the water was consequently clean.

The constant removal of carbonate of lime from underground rocks gives rise to the formation of long subterranean tunnels, cavities, and caverns, in limestone countries. Sometimes the roofs of these cavities, when near the surface, fall in and engulf brooks and rivers. In this way mud, sand, and gravel, with the remains of plants and animals, are swept below ground, and sometimes accumulate in deposits there. This has been the origin of ossiferous caverns, and of the loam and breccia, so often found in them. In many limestone districts the general drainage is withdrawn from the surface, and, sinking underground into the numerous channels which have been formed in the rock,

contain quite enough carbonic acid for the solution of carbonate of lime, even to saturation of the water with that mineral; while, the less the overplus of the acid, the more readily will the mineral deposition take place.

gives rise to subterranean rivers, which, after a long course, may issue to the surface again in a totally different surface-area of drainage to that in which they took their rise. In such districts, too, lakes may be formed by the giving way of the roofs of subterranean caverns; and by the same process valleys may be deepened, or, perhaps, even formed.

The influence of carbonated water, and of water containing alkaline carbonates, in decomposing and effecting pseudomorphic changes in rocks, has already been referred to.* Even when we have no access to the rocks underneath, we can often form a conception of the metamorphism which circulating water is effecting upon them, by analysing the composition of the water, which rises again to the surface in springs. Carbonate of lime is the main mineral constituent of spring-water; but there occur also very commonly sulphate of lime, carbonate of magnesia, and chloride of sodium. When the contained mineral ingredients are in such abundance as to form a deposit when the water evaporates round the spring, they give specific names to the springs, as calcareous springs, ferruginous or chalybeate springs, and siliceous springs.

Thermal springs are so called from their warm temperature. They are common in volcanic regions, but also occur more rarely at a distance from volcanoes. They are much more highly impregnated with mineral matter than cold springs. The warm springs of Bath have a mean temperature of 120° Fahr., and contain sulphates of lime and soda, and chlorides of sodium and magnesium. Professor Ramsay has calculated that if the annual discharge of water could be evaporated on the spot, the mineral contents would form a square column 9 feet in diameter, and 140 feet in height.† Silica is sometimes contained abundantly in the water of thermal springs, as in the case of the *siliceous sinter* deposited round the Geysers, or hot-springs of Iceland. One of these deposits is said to be two leagues in length, a quarter of a league wide, and a hundred feet thick. Similar deposits also occur in other parts of the world, as round the hot springs of St. Miguel and Terceira, in the Azores, and in the form of chalcedony round those of New Zealand. Cold springs also, in some instances, deposit siliceous matter; but in these the silica is generally combined with alumina, oxide of iron, and other bases. In all these cases, evaporation of the water takes place, and the silica is deposited in consequence of that evaporation.‡ Bischof attributes the formation of quartz crystals in cavities, and of compact quartz in veins, to the total evaporation of water containing silica in solution, and trickling down the sides of such cavities. He points out the im-

* See *ante*, pp. 362-5. † Ramsay, *Physical Geology and Geography of Britain*, p. 160.

‡ In parts of India silliceous stalactites occur, a specimen of one having been presented to the Museum of Irish Industry, by Mr. Lovell, Retired Inspector of Hospitals.

possibility of ascending springs depositing the quartz, inasmuch as these must be full of water, and therefore total evaporation of successive films of water could not take place. He regards the formation of quartz crystals in drusy cavities as the result of a similar evaporation of water, containing silica, which has filtered through the adjoining rock. Agates, chalcedony, etc., show very distinctly the successive deposition of films of silica.

2. The **Mechanical Action** of underground water consists in the removal of the finer particles of rocks in suspension. By this means the cohesion of large masses is sometimes so far weakened that they sink down, or are detached and fall off to lower levels. This usually happens on cliffs or sloping ground, where the rocks are traversed by joints, or consist of strata among which there are some of a loose porous nature, easily disintegrated by percolating or flowing underground water. Large portions of cliff or slope may thus be launched down, so as to obstruct a valley, and even pond back its drainage. These dislocations, caused by underground water, are termed *landslips*. They are common in hilly countries. The well-known fall of the Rossberg, behind the Rigi, in 1806, is a striking example. After a rainy summer the side of the mountain, consisting of sloping beds of hard red sandstone and conglomerate, resting upon soft sandy layers, gave way, and thousands of tons of solid rock swept across the valley of Goldau, burying four villages, with about 500 of their inhabitants.

Another remarkable instance occurred on the coast of Dorset, when a mass of chalk slid over the surface of a bed of clay down into the sea, leaving a rent three-fourths of a mile long, 150 feet deep, and 240 feet wide, the whole mass on the seaward side of it, with its houses, roads, and fields, being cracked, broken, and tilted in various directions, and thus prepared for being more easily carried off by the action of the sea.* Far larger instances of ancient landslips, of which no record is known, and which took place perhaps before historic times, or even before the country was inhabited by man, may be observed in some parts of the south-west coast of Ireland. On the coast west of Bearhaven in County Cork, and west of Brandon Head in County Kerry, as also in Derrymore Glen, between the mountains called Baurtregaum and Cahirconrea, there are great cliffs, 800 feet high, which from their confused and irregular positions are nothing but a heap of broken ruins, their cracks and dislocations being superficial only, or not extending below the level of the sea. Other remarkable landslips occur on the coast-line between Portrush and Belfast.† Similar falls, on a great scale, have taken place also in Mull, Raasay, and Skye, where the great plateaux of tertiary basalt rest upon oolitic and liassic strata.

* Conybeare and Buckland, in Lyell's *Principles*, i. 537.

† See Portlock's *Geological Survey of Londonderry*.

3. Brooks and Rivers.

a. Chemical Action.

There can be no doubt that the water of streams acts chemically upon rocks, in the same way as is done by rain and spring water. This is particularly observable in limestone districts, where streams not only erode but dissolve the rock, their action in this respect being greater when they drain off peaty ground, and consequently absorb more carbonic acid. The nature of the chemical reaction of terrestrial water upon rocks is well shown by the analysis of river water, for in river water, more particularly when taken from where it approaches the sea, we have the substances in solution which are finally removed from the land and carried into the sea.

According to the analyses collected by Bischof,* the river waters of Western Europe, including Great Britain, contain in solution variable proportions of the carbonates of lime, magnesia, and soda ; of silica ; of peroxides of iron and manganese ; of alumina ; of sulphates of lime, magnesia, potash, and soda ; of chlorides of sodium, potassium, calcium, and magnesium ; of silicate of potash ; of nitrates, and of organic matter. Of these mineral matters as little as a total of 2·61 in 100,000 parts of water were found in a mountain stream 3800 feet above the sea, and as much as 54·5 parts in the 100,000 in the waters of the Beuvronne, a tributary of the Loire above Tours. The mean of the whole is about 21 parts of mineral matter in 100,000 of water. Carbonate of lime usually forms the full half of this mineral matter, its mean quantity being 11·34. The next most abundant mineral is sulphate of lime, which in some rivers forms nearly half of the dissolved mineral matter. As much as 4·88 parts of silica dissolved in 100,000 of water have been found in the Rhine, near Strasburg, the greatest quantity of dissolved alumina being 0·71, in the Loire, near Orleans. The quantity of mineral matter in the Thames, near London, is about 33 in the 100,000 parts of water, 15 of which, or nearly half, are carbonate of lime. Bischof calculates that if the mean quantity of carbonate of lime in the Rhine be assumed as 9·46 in 100,000 of water, which it is at Bonn, then, according to the quantity of water estimated by Hagen to flow at Emmerich, enough carbonate of lime is carried into the sea by the Rhine, for the yearly formation of three hundred and thirty-two thousand millions of oyster shells of the usual size. If we allow two square inches for each oyster to stand upon, and that three oysters, one above another, would be one inch high (quantities within the truth), then this number of oysters would form a cube 560 feet in the side, or they would make a square layer a foot thick and upwards of two miles in the side.

All the mineral substances carried in solution by rivers into the

* *Chemical Geology*, vol. i. p. 76. He gives a table of forty-eight different analyses.

sea, are derived from the waste of the land, either directly by the action of the rivers themselves, or through the prior working of rain and springs. If, therefore, we could collect and make visible all this unseen material, it would form a vast mass, and would show how important, in a geological point of view, are the silent chemical changes carried on by percolating and running water.

β. Mechanical Action.

(1.) **Destructive.**—Moving water acts mechanically upon rocks, by rubbing sand, silt, gravel, and boulders upon them. This happens in the bed of every stream. The detritus is employed as a means of eroding the solid rock, and is itself at the same time still further comminuted. Large blocks of rock are thus by degrees worn into gravel, then into sand, silt, or mud, and at last, in this finely levigated state, the ruins of hills and mountains are swept out to sea.

By the attrition of the water-borne detritus upon the rocks, the beds of streams are channelled into grooves, widened and deepened. Where an eddy forms, and sand or gravel is consequently kept whirling upon the rocky bottom, a cavity called a *pot-hole* is formed, sometimes several feet broad, and a yard or more in depth. These pot-holes are often worn away till two or more coalesce, and wide and deep pools are thus eroded in the bed of the stream.

While it is only by the friction of the detritus which it sweeps along that running water acts mechanically upon rocks, we must remember that this detritus is to a large extent supplied to rivers by the action of those processes of "weathering" already described. Where the action of weathering is more rapid than the power of the stream to sweep away the fallen debris and directly undermine the banks, sloping declivities are produced. Where, on the other hand, the stream cuts into the rock faster than weathering does, a ravine is formed.

The form of a river-bed is largely determined by the varying nature of the rocks through which the river has to cut its way. Sudden changes in the geological structure or lithological character of the rocks give rise to waterfalls. If, for instance, a stream, in gradually deepening its channel, encounters in one part of its course a rock much softer than the rocks higher up the stream, the softer rock will be more rapidly worn away, and at the point of junction, where the harder rock overlies the other, a cascade will gradually be formed. Cascades and waterfalls dig deep holes and black pools below the ledges over which they fall, and often undermine those ledges, and thus break them away, block by block, much faster than mere abrasion could remove them. Cataracts cut their way back in all rivers, whether in the ravines of mountains, or when they fall from one plain or one table-land to another, as in the case of the Falls of Niagara and

others. The ravine that the river St. Lawrence has excavated for itself by the recession of its Falls is 7 miles long, 200 to 400 yards wide, and 200 to 300 feet deep, and would require something like 35,000 years for its production, at the present rate of progress.*

Perhaps no part of the world illustrates the erosive power of long-continued river-action on a more magnificent scale than the great table-land watered by the Rio Colorado and its tributaries (see Frontispiece). These rivers flow for hundreds of miles through gorges called cañons several thousand feet deep, which they have gradually cut out of the rocks. The grand Cañon of the Colorado is 300 miles long, and in some places 6000 feet deep.†

(2.) **Transporting.**—In the gradual erosion of their courses, rivers produce a large amount of detritus, which, together with what they receive from the washing of the land by rain, they sweep out to sea. The blocks accumulated in mountain torrents are usually crags that have been gradually loosened by weathering from the neighbouring cliffs or slopes, or have been undermined by the abrasion of the water, and have then fallen into the bed of the river. These blocks, arresting the force of the stream, are immediately attacked by it, and eventually become smooth and rounded by the attrition of the water charged with sand and gravel. When sufficiently rounded, some greater flood than usual sets them in motion, to receive still further rough treatment, and to become converted into tools for the breaking up of others, till at length the massive crag is rolled forward into the river in the form of small round pebbles.‡ These undergo a continuation of the same mechanical operation, till they are delivered by the river into the sea in the shape of grains of sand or fine mud. Clouds of such mud discolour the sea off the mouths of great rivers, such as the Amazon and Orinoco, even for many scores of miles out of sight of land ; and the great ocean currents may carry it on, still slowly sinking through greater depths, even for many hundred miles further, before it finally settles to rest in some tranquil hollow of the bed of the ocean.

The transporting power of rivers is greatly augmented in countries where the winters are severe enough to freeze the rivers. Ice forming along the banks encloses gravel, sand, and even large blocks of rock, which, when the spring comes, are lifted up by the ice and carried down the stream. Ground-ice likewise forms frequently on the bottoms of the rivers, and rises in cakes to the surface, carrying with it the mud or stones lying on the bottom, which are then swept seaward.

* Lyell's *Principles of Geology*, chap. xiv. See, however, *Coal and its Topography*, by J. P. Lesley, 1856, p. 169.

† See *Exploration of the Colorado River of the West*, by Ives and Newberry, 1861, where some admirable engravings and woodcuts are given of the more striking features of the marvellous scenery of these regions.

‡ See *postea*, p. 426, for a reference to the gravel detritus of the Rhine.

The researches of the late Mr. Hopkins have shown that the power of water to move bodies that are in it increases as the sixth power of the velocity of the current. Thus, if we double the velocity of a current, its motive power is increased 64 times; if its velocity be multiplied by 3, its motive power will be increased 729 times; if by 4, 4096 times; and so on.* In studying the mechanical force of water upon rock also, it is necessary to bear in mind that all earths and stones lose fully a third of their weight when suspended in water. These considerations enable us to understand more readily the fact of blocks of rock, many tons in weight, having been removed from breakwaters and jetties, and carried sometimes many yards during great storms, as also of still larger blocks hurried along by floods, etc. The rolling power of water upon stones lying in its bed depends greatly on their shape also, the same current being easily able to roll along, in the form of rounded pebbles, pieces of rock which it would be quite unable to move if they were in the shape of flat slabs; while, conversely, flat slabs or flakes would float more easily, or sink more slowly, than rounded or square-shaped fragments of the same weight and cubic contents. Flakes of mica, as Sir C. Lyell observes, therefore, might be floated and transported onwards where grains of quartz, even though lighter than the mica, would sink; and, on the other hand, rounded quartz pebbles might be rolled forward where smaller and flatter pieces, in the shape of shingle, would be brought to rest.

Mr. Babbage, in treating of this subject,† supposes the case of a river, the mouth of which is 100 feet deep, delivering four varieties of fine detritus into a sea which has a uniform depth of 1000 feet over a great extent, which sea is traversed by one of the great ocean currents, moving with a certain given velocity.‡ He takes for granted that the four varieties of detritus are such as, from their size, shape, and specific gravity, would fall through still water, the first ten feet per hour, the second eight feet, the third five feet, and the fourth four feet. The combined effect of the downward motion of the detritus and the onward motion of the water, would then bring the first variety to the bottom of the sea, at a distance of 180 miles from the river's mouth, and strew it over a space 20 miles long; the second variety would only begin to reach the bottom 225 miles from the river's mouth, and would be spread over 25 miles, and so on, as in the following Table :—

No.	Velocity of fall per hour.	Nearest distance of deposit to River mouth.	Length of deposit.	Greatest distance of deposit from River mouth.
	Feet.	Miles.	Miles.	Miles.
1	10	180	20	200
2	8	225	25	250
3	5	360	40	400
4	4	450	50	500

We should thus have, proceeding from the same river, and poured into the sea either simultaneously or at different times, four different and widely separated patches of mud or clay formed on the sea bottom. This subject was suggested to

* Presidential Address to *Geol. Soc. London* for 1852, p. xxvii.

† In a paper, of which an abstract appeared in the *Journal of the Geological Society*, November 1856.

‡ The supposed velocity of the river and ocean current is not stated in the abstract, but from the calculation would appear to have been taken at two miles per hour.

Mr. Babbage from his observing the extreme slowness with which a very fine powder, even of a very heavy substance, such as emery, subsides in water, and he speaks of mud-clouds being suspended in the depths of the ocean, where the density of the water increases, for vast periods of time.

Dr. Livingstone (in his *Missionary Travels in South Africa*, p. 598) describes rivers which ordinarily have more sand in them than water. He says, "We came to the Zingesi, a sand rivulet in flood. It was sixty or seventy yards wide, and waist-deep. Like all these sand rivers it is for the most part dry; but, by digging down a few feet, water is to be found, which is percolating along the bed on a stratum of clay. . . . In trying to ford this, I felt thousands of particles of coarse sand striking my legs. . . . These sand rivers remove vast masses of disintegrated rock before it is fine enough to form soil. . . . The shower of particles and gravel which struck against my legs gave me the idea that the amount of matter removed by every freshet must be very great. In most rivers where much wearing is going on, a person diving to the bottom may hear literally thousands of stones knocking against each other. This attrition being carried on for hundreds of miles in different rivers, must have an effect greater than if all the pestles and mortars and mills of the world were grinding and wearing away the rocks."

The temporary damming up of rivers, and subsequent breaking down of the barrier, and escape of the lake formed above it, produce sometimes the most remarkable instances of the power of moving water. Rocks as big as houses are thus set in motion, and carried sometimes for very considerable distances down the valleys.*

The amount of mechanical work done by rivers can be estimated by examining their waters at different periods, and determining their solid contents. When this is done by evaporating the water, the result gives both the mechanically suspended mineral matter, and also that which was chemically dissolved in the water.

The total mineral matter carried down by the Ganges into the sea, according to Everest, is 6,368,077,440 cubic feet per annum. Lyell calculates that for the transport of this quantity, it would require a fleet of 2000 Indiamen, each of 1400 tons, to start every day throughout the year. Such a mass of matter would cover a square space fifteen miles in the side every year with mud a foot deep, or would raise the whole surface of Ireland one foot in the space of 144 years. The Brahmapootra probably carries an equal quantity.

The Mississippi, according to the measurements of Messrs. Humphreys and Abbot, conveys every year into the Gulf of Mexico 19,500,000,000,000 cubic feet of sediment.†

Mr. Barrow calculated that the Yellow River (Hoang Ho), in China, carried down into the Yellow Sea 48,000,000 of cubic feet of earth *daily*, so that, assuming the Yellow Sea to be 120 feet deep, an English square mile might be converted into dry land every seventy days, and supposing its area to be 125,000 square miles, the whole would be made into terra firma in 24,000 years.

These examples are cited here in illustration of the nature and extent of the transport of detritus by rivers. But additional instances will be given in a subsequent chapter, when we come to speak of the

* See Lyell, as above; also Jameson's *Mineralogy*, vol. iii., and De la Beche's *Manual and Geological Observer*.

‡ *Report upon the Physics and Hydraulics of the Mississippi*, 1861.

sum total of effects produced by all the various agents of waste in the general denudation of the land. In the meantime, it may be remarked that the annual amount of sediment carried into the sea by a river, represents the extent to which the area drained by that river has had its surface lowered in one year. But this lowering is not equally distributed over the whole basin of drainage. It is greatest along the lines by which the superfluous water is conveyed back to the sea, that is, along the valleys, and least along the ridges and table-lands. Thus the drainage of a country, as is proved by the river-borne detritus, necessarily gives rise to a system of valleys ranging from the mountain-tops outward and downward to the sea. This subject, however, will be discussed in Chapters XXV. and XXVI.*

(3.) **Reproductive.**—When a river reaches a level tract on which its motion is slow, and over part of which it can flow in flood, it deposits its sediment, and forms what is called *alluvium*. This deposit, consisting of earth, silt, mud, or gravel, may be laid down either on one or on both sides of the river, where it forms a level tract, the surface of which is increased by each fresh layer of sediment, until even the highest flood can no longer cover the plain. As the stream continues to deepen its channel, and as from inequalities in the nature of its bank, sometimes of the most trifling kind, it is turned from side to side in wide curves and loops, it cuts into its old alluvium, and makes a newer plain at a lower level. Further erosion of the bed enables the stream to attack this later alluvial deposit, and form a still newer and lower one. Thus the river comes to be bordered with a succession of terraces, each of which represents a former flood-level of the stream. In studying the old river-terraces of a country we have also to consider whether they indicate former periods of greater rainfall, and point to any movement of upheaval of the interior which would quicken the erosive action of the streams, or any depression of the interior or rise of the seaward tracts, which would diminish that action and increase the deposition of alluvium.

It is evident, however, that the deposition of any sediment on the land is only temporary, and that the inevitable fate of all the waste of the land is to be ultimately carried to the ocean.

The materials borne in suspension by a river, or rolled along its bed, are deposited at the river mouth, in a lake, or in the sea. As they are pushed forward the land gains by the formation of a flat alluvial tract, to which the name of *delta* has been given, from its resemblance to the Greek letter Δ, the apex of the letter however pointing up the river, and the base fronting the sea or lake. If we follow the course of

* For clear and eloquent description of the erosion of valleys by river-action, the student will find no work in the English language equal to Playfair's *Illustrations of the Huttonian Theory*. See, in particular, note xvi. *On Rivers and Lakes*.

any river from its sources to its termination, we perceive that the size of the river and the volume of water it contains is continually increased by the accession of tributary streams, now on one side and now on another. No stream ever flows out of a river, nor, except in extremely rare cases, does the river ever divide into two streams, save for a short distance, where a comparatively small island may have been formed in some flat or rocky part of its bed. When, however, we follow a river down to a low flat country on its approach to a lake, or to a part of the sea at the head of a bay or gulf, or where no oceanic currents sweep across its mouth, we then find the river split up into two or more branches by the formation of a delta. In the delta part of a river an entire change takes place in its nature ; instead of continually receiving fresh accessions of water, and so becoming larger and larger, the river now splits into smaller and smaller channels. In the upper parts fresh accessions of earthy matter are brought into it, but now it begins to deposit the sediment it contains. In fact the river properly ceases at the head of the delta, where its mouth originally was, and its water merely finds its way out into the lake or sea below in the best fashion it can, through the mud with which it has choked its own mouth.

The Rhine, when it enters Holland, is lost in a great deltoid flat, among a number of bifurcating channels, in which its waters are mingled with those of the Meuse, the Sambre, the Scheldt, and other rivers, which have all contributed to produce the low marshy ground that skirts the coast of Belgium, and forms nearly the whole of the Netherlands. So obviously is the delta of the Nile the production of that river, that Herodotus remarked that "Egypt was the gift of the Nile," and that the sea probably once flowed up to Memphis, now more than 100 miles from the coast-line, the old gulf having been filled up by the Nile mud, as the Red Sea would be filled up if the Nile were turned into it. The edge of the present delta, which is 150 miles wide, is, however, now swept by a powerful current, which carries off all detritus delivered into it, and thus future increase is prevented. Otherwise the Nile would by this time have formed a long tongue of land projecting into the Mediterranean, just as the Mississippi has projected a tongue of land 50 or 60 miles long into the Gulf of Mexico, having previously filled up the inlet which formerly penetrated from that sea deeply into North America, and received the rivers more than 100 miles inland from the present coast.*

The Ganges first bifurcates at a distance of 220 miles from the present coast, and the river may be said, like the Rhine on entering Holland, properly to terminate there, for below that it splits into numerous channels among marshy ground, which it has formed in conjunction with the Brahmapootra and other rivers. This muddy flat stretches for 260 miles along the head of the Bay of Bengal. Dr. Hooker, in his description of this district,† speaking of its eastern border, remarks that "the mainland of Noacolly is gradually extending seawards, and has advanced four miles within twenty-three years. The elevation of the surface of the land is caused by the overwhelming tides and north-west hurricanes in May and October ; these extend thirty miles north and south of Chittagong, and carry the waters of the Megna and Fenny (branches of the Brahmapootra) back over the land in a series of tremendous waves that cover islands of many

* Lyell, *Principles*, vol. i. chaps. xviii. and xix.

† *Himalayan Journals*, vol. ii., p. 341

hundred acres, and roll three miles into the mainland. On these occasions the average earthy deposit of silt separated by micaceous sand is an eighth of an inch for every tide, but in October 1848 these tides covered Sundeep island, deposited six inches on its level surface, and filled up with mud ditches several feet deep." The bifurcations of the Brahmapootra commence even further from the sea than those of the Ganges, and there is a great flat of more than 100 miles in width between the two, in which a number of lesser streams, proceeding directly from the southern slopes of the Himalayas, likewise bifurcate, some of them beginning to do so at 300 miles from the sea-coast. It would appear, therefore, that we have here a vast river-deltoid deposit, covering an area of something like 50,000 or 60,000 square miles, or more than that of England and Wales. An Artesian well, 481 feet deep, was bored at Calcutta, of which the upper 400 feet at least may be stated as river-deposit, although giving evidence at one or two places of the land having formerly been at a higher level, and the river therefore having brought coarser materials than now.* Large and thick as this great mass of mere river-washing may appear, it does not represent the whole quantity brought down, since we learn from Lyell that outside the part which may be called actually land, there is a gradual slope out to sea of more than 100 miles—the water slowly and regularly deepening from 4 to 60 fathoms. In the centre of this submarine slope, too, is a deep hole about 15 miles across, called "the swatch of no ground," in which no bottom is found with 100, or even 130 fathoms of line, giving us apparently a measure of the depth the water would have had over the whole neighbouring space if it had not been for the mud brought down by the river.

In a paper on recent changes in the Delta of the Ganges, by Mr. Ferguson,† it is shown that 2000 years ago large parts of the now densely peopled plains round the lower part of the Ganges must have been mere swamps; that the Delta, properly so called, cannot have been fit for extensive occupation before the fourteenth century, and that parts of Assam, now uninhabitable swamps, will in a few centuries become dry plains. He also says, that in the "swatch of no ground" there is even as much as 300 fathoms with "no bottom," and shows how the action of the tidal currents has been such as to keep this central channel swept clear of the deposit that has been thrown down around it.

The great rivers, however, which do not block up their own mouths with a delta, do not the less on that account carry down sediment into the sea. The Rio Plata and the Amazon have their mouths swept comparatively clean, partly by the force of their own current carrying out the detritus into deep water, and partly by the oceanic currents which travel past their mouths aiding them in this transport. The river St. Lawrence is greatly strained of sediment by having to pass through the large lakes which it must first fill up and convert into dry land before it can begin to form a delta at its mouth.

The Thames and Severn, and other smaller rivers of our own islands and other parts of the world, fall into the tidal waters with too short and too rapid a slope to commence the formation of a regular delta, the falling tide helping the river-flow to scour out the embouchures, although many large sandbanks are formed in them. The set of the currents in the German Ocean seems to be directed from the continental and against the English shores; but where any part of the latter is protected from the sweep of those currents, as in the deep bight called the Wash, between Norfolk and Lincolnshire, there the rivers make a deltoid flat or great marsh, scarcely above the level of the sea. Such are "the fens" of Cambridge and Lincoln, a tract of about 2000 square miles, the product of the rivers Witham, Welland, Nen, Ouse, Cam, and others. In the tropics these fens would have a huge mangrove swamp along their seaward edge, while inside that there would be a jungle like the Sunderbunds of the Gangetic delta.

* Lyell, *Op. cit.*, chap. xix.

† *Quart. Journ. Geol. Soc.*, xix.

In the alluvial deposits formed by rivers, the remains of land and fresh-water plants and animals are often entombed and preserved. Large quantities of drift-wood are often carried down by floods; and bodies of large animals are swept off to be buried in the delta, or even to be carried out to sea. Hence, in deposits formed at the mouths of rivers, we may always expect to find abundant terrestrial organic remains.

4. Frozen Water.

When fresh water under ordinary circumstances is cooled down to 32° Fahr. it passes into the solid state, and is then known under the names of frost, snow, and ice. In this form, however, it is not withdrawn from the general system of circulation. It still continues to move from land to sea, but in doing so is endowed with new powers as a geological agent.

a. Frost.

It is now well known that when water in cooling reaches a temperature of 39¼° Fahr. it begins to expand, and in this expanded state becomes solid at 32°. If rain soaks into soils and rocks, and fills up either the small pores, or the crevices, joints, and fissures, by which all rocks are traversed, and this water then freezes, the expansion which accompanies its conversion into ice exercises a powerful mechanical force, the effect of which will be either the disintegration of the particles in the one case, or the breaking and rending asunder of the larger masses in the other. On mountain summits and sides, subject to great vicissitudes of temperature, this agency exerts no mean effect. The hardest rocks may be broken up by it, and enormous blocks ultimately displaced and toppled over precipices, or set rolling down slopes, to suffer still further fracture, and produce still greater ruin in their fall. We see its effects, too, in the way in which, after a strong frost, the soil of fields and soft roads is found to be loosened and pulverised.

Few men live in situations enabling them to observe, and of these still fewer have the ability or the inclination to record, the amount of this agency in the remote places where it is greatest. Its amount, however, may be estimated by the piles of angular fragments, lying at the foot of crags and precipices, or sometimes on the steep summits of the mountains, where they are the ruins of formerly existing "tors" and pinnacles. Captain Beechy, in his voyage towards the North Pole, describes the amount of this action as very great in Spitzbergen. He found the mountains rapidly disintegrating from the great absorption of wet during summer, and its dilatation by frost in winter. "Masses of rock were, in consequence, repeatedly detached from the hills, accompanied by a loud report, and falling from a great height, were shattered to fragments at the base of the mountain, there to undergo

a more active disintegration." Soil was thus formed up to 1500 feet above the sea.* Similar observations were made by Dr. Kane in North Greenland, where the waste of the cliffs by frost goes on every year on a great scale.†

The effects of frost upon rivers, in enabling them to transport sand, mud, gravel, and large blocks of rock, have been already referred to.

β. Snow.

When rain or aqueous vapour is cooled down to the freezing point, as it passes through a cold layer of the atmosphere, it is frozen, and falls to the earth as hail or snow. Hailstones, when of large size, are often destructive to cattle and vegetation. Snow, when it does not fall deeply, and remains stationary and unmelted, exercises a protective influence on the face of the land, shielding rocks, soils, and vegetation from the disintegrating effects of frost. When, however, it accumulates to a great depth on forests and woodlands, its weight sometimes breaks down branches and even bends down entire trees. In like manner, when the deep accumulations of snow are formed on steep slopes, they are apt to be loosened by thaw, by springs, or by their own increasing weight, and large masses, called in Switzerland *avalanches*, are let loose, and sweep down into the valleys, carrying ruin and desolation as far as they reach. In the more exposed parts of the chief routes in mountainous countries, exposed to such snow-slides, archways are built over the roads, and woods are protected with care, as a bulwark against the descending snow.‡ The rapid thawing of snow gives rise to great floods. Hence, in Switzerland, a warm south wind in early summer may, by quickly melting the snows on the mountains, give rise to disastrous inundations, even though the weather should be fine and rainless.

γ. Glaciers.

When mountains are covered by perpetual snow, all the parts so covered are protected by this envelope from change. In such situations, however, the moving power of water takes another form, that of the glacier, or "river of ice." The lower border of the perpetual snow-mass passes into ice, chiefly from the pressure of the mass above, but partly from the alternation of melting and freezing temperatures, just as snow on the roof of a house forms icicles at its lower edge, when some of it is melted by the sun or the warmth of the house, and re-frozen by the cold from radiation or the next night's frost. This ice accumulates in the valleys, and is frozen into a solid or nearly solid mass, called a glacier. Glaciers sometimes fill up valleys

* See Sir J. Richardson's *Polar Voyages*, p. 207.

† See Kane's *Arctic Explorations*, and Hayes' *Open Polar Sea*.

‡ See *ante*, p. 382.

of the Alps twenty or thirty miles long, by a mile or more wide, to the depth of 600 feet, or more. Although apparently solid and stationary, they really move slowly down the valleys, and carry with them, either on the surface, frozen into their mass, or grinding along the bottom, all the fragments, large and small, from blocks many tons in weight, down to the finest sand and mud, which rain, and ice, and the friction of the moving glacier itself, detach from the adjacent rocks. The glaciers of the Alps descend to a vertical depth of nearly 4000 feet below the line of perpetual snow, before they finally melt away, and leap forth as rivers of running water. The confused pile of materials, of all sorts and sizes, which they there deposit, is called the *moraine.* This word is also applied to the lines of blocks that are carried along on the surface of the ice. When these lines of rock-rubbish run along the margin of the glacier they are called the *lateral moraines*, the one at the end of the glacier being styled the *terminal moraine.* It is easy to understand that a glacier slipping down its valley must bear on its sides the blocks that fall from the adjacent cliffs, just as a river would carry down the sticks and leaves from the woods on its banks. A line of debris may thus be seen on each side of the glacier, and if two ice-streams unite, the two lines of transported substances on their adjacent sides would likewise unite, and be carried down as a *medial moraine* along the centre of the stream below the junction. In this manner, if a glacier have many tributaries in its upper parts, the lower portion of it may have many medial lines of moraine, and in some cases so many as to be entirely covered with a confused coating of debris.*

The glaciers of the Alps, and other mountainous regions in temperate or intertropical latitudes, are only found in the valleys, and are to be regarded as the drainage of the snow-fall, just as rivers are the drainage of the rain-fall of a country. But in the polar regions the land is enveloped in a vast sheet of snow or ice, which, augmented by constant falls of snow upon its surface, moves slowly but irresistibly over the land, down to the sea. Greenland is a great continent buried under such a pall of snow. All its inequalities, save the mere sharp mountain summits, are concealed, and the snow pressing down the slopes, and even mounting over the minor hills, passes beneath into compact ice. From all the main valleys great tongues of ice, 2000 or 3000 feet

* For descriptions of the glaciers of the Alps, and the cause of the motion of glaciers, see the works of Agassiz and Charpentier, J. Forbes, and Dr. Tyndall; also papers on glacier motion, by Canon Moseley, *Proceedings of the Royal Society*, xvii. 202; by the late Mr. Hopkins, *Theoretical Investigations on the Motion of Glaciers*, Cambridge, 1842, and *Camb. Phil. Trans.* 1864; and by Mr. Croll, *Phil. Mag.*, March 1869 and September 1870; for the glaciers of the Himalaya, Dr. Hooker's *Himalayan Journals*, and papers by Captain Godwin-Austen in the *Journal of the Geographical Society*. The student of glacial action should not fail to consult a brief but valuable "Report on Ice as an Agent of Geologic Change," in the *Report of the British Association* for 1869, p. 171.

thick, and sometimes 50 miles or more in breadth, are thus pushed out to sea, where they break off in huge fragments, which float away as icebergs.*

The river of water that always springs from the end of a glacier, is, of course, quite unable to move the larger blocks which have been carried down by the glacier, and they remain in the terminal moraine until they are worn away, or broken up by atmospheric influences. The river, however, carries off at once the fine mud and impalpable powder† derived from the grinding action of the glacier, and flows as a dirty yellowish or greenish white stream, until it reaches the sea, or some great lake like that of Geneva, in which the sediment may be deposited. The Rhone that has become purified in the Lake of Geneva is, shortly after issuing from it, contaminated by the Arve and other rivers below. The Rhine deposits its own proper sediment in the Lake of Constance, and the muddy rivers that descend from the northern slopes of the Bernese Oberland are likewise filtered by lakes, so that the glacial detritus of Switzerland is not carried into the North Sea, as it is by the Rhone into the Mediterranean. Much of the mud poured into the Adriatic by the Po must come from the glaciers of Mont Blanc, and its neighbourhood, that descend towards the Val d'Aosta. In like manner, from the same great central group of European mountains, the finer detritus delivered from the glaciers of the Tyrol by the Inn into the Danube, is borne eastwards and thrown down in the Black Sea. We shall see in a subsequent chapter, that, during a time known as the Glacial Period, when the quantity of snow and ice in Europe was enormously greater than it is now, the swollen muddy rivers from the Alps laid down a vast amount of mud, now called *loess*, over the valleys and plains from the North Sea to the Euxine.

The amount of fine sediment which discolours all streams that escape from the melting ends of glaciers, is an index to the amount of erosion which glaciers are ceaselessly carrying on. This erosion is effected not by the mere contact and pressure of the ice upon the rocks, but by means of the fine sand, stones, and blocks of rock, which, falling between the sides of the glaciers and the bounding rocks, or through *crevasses* or rents of the ice, are ground down against the sides and bottom of the valley as the ice moves downward. The hardest rock is thus worn away,

* See Kane and Hayes, in the works already cited; also Rink, *Journ. Geograph. Soc.*, vol. xxiii.

† The ice of a glacier seems in its lower part to be always full of little bubbles, containing small nests of this dirty powder. The author observed in the summer of 1860, that at some of the hotels in Switzerland (especially at Chamounix, at the Hotel des Londres), ice was provided at the table d'hote. This was of course glacier-ice, and on putting a piece of it into a glass of water, first one and then another of the little bubbles in the ice burst, as its walls melted, and a cloud of sediment was discharged into the water, so that in the space of ten minutes the glass of water, which was at first quite clear, became as turbid as if a spoonful of milk had been dropped into it.

and, if the ice retires from it for a while, we see its surface worn smooth and covered with fine striæ and deeper grooves, which show where the grains of sand or points of stones were kept fast in the ice, as in a vice, and scored the rock over which they were pushed. Inequalities in the power of resistance of the rock give rise to a wavy undulated surface, the prominences or harder parts being usually smoothed off into the shape of a whale's back, and in that form known as *roches moutonnées*. They, as well as the hollows or softer parts, are scored from end to end with striæ and grooves in the direction in which the ice has moved.

The existence of softer parts in a rock has enabled the ice of a glacier to scoop out not only long confluent hollows, but even basin-shaped cavities, which, on the retirement of the ice, are filled with water and form lakes, unless choked up with the glacial detritus. A similar kind of erosion may take place even without any marked variety of texture in the rock, if the glacier is, as it were, strangled by a constriction of the valley, and is made to exert an enormous grinding action on the rocks, as it squeezes itself through or over the obstruction. Running water tends to fill up lakes, not to form them, and, as Professor Ramsay first pointed out, the only general agent which, so far as we know, can dig out cavities in any solid rock, or even in clay, is glacier-ice. The conditions necessary for this operation are probably never fully complied with, except under a great sheet of ice covering the land, like that of Greenland, where the grinding power of the ice is not interfered with by the general subaerial waste. In the case of a glacier valley, the bottom, as the ice retires, is filled up with moraine rubbish, and the actual rock is not seen, except in the prominent *roches moutonnées*. But in the case of a continental ice-sheet there is little or no superficial moraine detritus; and when the ice creeps back and allows the ice-worn rock-surfaces to be seen, the only detritus which can cover up the scooped-out rock-basins is that which has been pushed along under the ice, that is, the *grundmoräne* or *moraine profonde* of Swiss geologists. This deposit, as it is wide-spread and often very deep, must doubtless conceal much of the surface on which the ice worked; but, on the rising-grounds, where it did not accumulate, and among the mountains, where the ice lingered longest, we may expect to find the rock-basins preserved. And it is, in fact, in such places that we do find them. The question of the origin of lake-basins will be discussed in Chapter XXVI. treating of Physiography.

CHAPTER XXIV.

THE SEA.

VIEWED as a great geological agent, the sea presents itself to us under four aspects:—1st, As a vast body of water in which the more soluble substances of the globe are held in chemical solution; 2d, As an important agent in modifying the distribution of climate; 3d, As one of the great powers employed in effecting the waste of the land; and, 4th, As the receptacle into which the debris of the land must ultimately come, and where the materials for new continents are accumulated.

1. Chemical Composition of the Sea.

The specific gravity of the sea is greater than that of fresh water, but varies in different parts of the globe, and even in adjacent parts of the same ocean. It is least near the mouths of rivers, and in polar regions, where it is mixed with the fresh water from melted ice. It is greater in low than in high latitudes. According to the determinations given by Von Bibra, the mean specific gravity of specimens of water from the Atlantic, Pacific, and German Oceans, was found to range from 1·0244 to 1·0287.*

Sea-water contains air and carbonic acid, as well as other gaseous substances. Observations off the coast of Algiers showed that the water, at the depth of 65 metres, contained from ·01 to ·02 of its volume of air, while in the region of St. Malo the proportion varied from 1-20th to 1-30th of the volume of the water.† The waters of the European seas, according to Vogel and Bischof, contain from ·7 to 2·3 parts by weight of carbonic acid gas in the 10,000 of water; but in the South Sea and Indian Ocean, only from ·045 to ·35 parts by weight in the 10,000.‡ It was apparently established, however, by experiments in the latter oceans, that the quantity of air, and especially of carbonic acid gas, increased with the depth from which the water was taken. Sulphuretted hydrogen and hydro-sulphuret of ammonia are present in sea-water, owing to the decomposition of its sulphates by organic matter.

The average proportion of saline constituents in sea-water is about

* Bischof, i. 97. † *Op. cit.* 115. ‡ *Op. cit.* i. 113, and 115, *note.*

three and a half parts in every hundred parts of water. They consist of the following salts:—*

	Percentage.
Chloride of Sodium (common salt) . .	75·786
Chloride of Magnesium . . .	9·159
Chloride of Potassium . . .	3·657
Bromide of Sodium . . .	1·184
Sulphate of Lime (gypsum) . .	4·617
Sulphate of Magnesia (Epsom salts) .	5·597
	100·000
Total percentage of salts in sea-water .	3·527

When sea-water is evaporated, the point of saturation for sulphate of lime is much sooner reached than that for rock-salt; 37 per cent of the water being required to be removed in the one case, and 93 per cent in the other.† Gypsum, therefore, must always be deposited before rock-salt, and it is possible for the point of saturation to be reached for gypsum in many cases without that for rock-salt being attained. This may be the reason that, although the sea contains sixteen times as much salt as it does gypsum, the latter more frequently occurs as a mineral deposit than the former, though not often in such great masses. It has been suggested that, in consequence of the greater specific gravity of sea-water increasing with the quantity of salt it contains, and the evaporation at the surface causing a perpetual increase in the salt of the surface water, a part of the water which holds a larger quantity of salt in solution than the rest may sink to the bottom of the sea, and that this process may be continued until the lower strata be saturated with salt, and precipitation take place. The circulating currents of the ocean, however, keep up such a constant mixture of its waters as would seem altogether to prevent this action; and even in deep hollows and basins, such as the Mediterranean, separated by a shallower bar (1320 feet at the deepest) from the bed of the ocean, the *traction* of the currents passing over this is sufficient, according to Maury, to prevent any accumulation of denser and salter water at the bottom.

In isolated seas, such as the Dead Sea, where the water is entirely saturated with salt, evaporation may, doubtless, cause a precipitation on its bed or along shallow shores. Here, and in shallow lagoons, such as the limans of Bessarabia, south of Odessa, that dry up in summer, we have the formation of rock-salt going on before our eyes.

There can be little doubt that inland seas and salt lakes are not necessarily portions of the great ocean left in hollows on the elevation of the land. In most, if not in all cases, their saltness is to be attributed to the fact that, as they have no outlet to the sea, their waters are constantly, as it were, boiled down by evaporation and become saline, the salts being derived by the various inflowing rivers from the dissolution of the rocks.

Notwithstanding the vast quantity of carbonate of lime carried down into the sea, observation shows that the quantity to be found in sea-water is commonly very small. In most analyses of sea-water it is not mentioned at all. Sea-water from Carlisle Bay, Barbadoes, indeed, was said to contain 10 parts in 100,000, and sea-water from between England and Belgium, 5·7 parts in 100,000, but in the open sea, at a distance from any land, it is said to be rarely if ever discoverable by analysis. The smallness of the quantity to be found in sea-water, compared with that in almost all rivers, is doubtless, in great measure, owing to the quantity of

* *Bischof*, i. 379.

† *Bischof*, *loc. cit.*

carbonate of lime constantly abstracted from sea-water by marine animals, in order to form their shells and other hard parts. When we consider the number and variety of fish and mollusca, crustacea, echinodermata, and polyps, that inhabit the sea, and especially when we look at the enormous bulk of the coral-reefs that are found within the tropics, we shall form some notion of the vast amount of carbonate of lime annually abstracted from the ocean. That it is abstracted more in one part than another, and yet the ocean maintains a nearly equal average, will not be surprising when we reflect on the extent of the great currents that traverse the sea, and look upon the entire ocean as one vast, slowly circulating system of moving water.

The quantity of free carbonic acid gas contained in the sea, is said, by Bischof, to be five times as much as is necessary to keep in a fluid state the quantity of carbonate of lime to be found in the sea. He argues, therefore, that it is impossible for any carbonate of lime to be precipitated in a solid form at the bottom of the sea by chemical action alone. No evaporation of water and gas can occur to a sufficient extent in the sea for precipitation to take place, as it does from the waters of calcareous springs. We are almost compelled, therefore, to conclude with Hutton, that all our marine limestones have been formed by the intervention of the powers of organic life, separating the little particles of carbonate of lime from the water, and solidifying them as parts of their own bodies.

Of the salts dissolved in sea-water, 8 to 15 per cent consist of chloride of magnesium, and 6 to 16 per cent of sulphate of magnesia. From the quantity of free carbonic acid in the sea, it is plain that these salts might be converted into carbonate of magnesia, but that if so, it would be kept in solution as a bi-carbonate (or sesqui-carbonate), as in the case of carbonate of lime. All that has been said, therefore, as to the necessity for calling in the aid of organic life to solidify carbonate of lime from the waters of the sea, "holds good in regard to carbonate of magnesia, and the more so, since this salt always separates later than carbonate of lime, even from fluids which have undergone a very high degree of evaporation."*

There is, however, this difficulty in this view:—The carbonate of lime is largely separated from the sea-water by being made to enter into the composition of the hard parts of marine animals in overwhelming proportion, whereas the percentage of carbonate of magnesia to be found in the hard parts of corals and mollusca does not usually exceed 1 or 2 per cent. Neither do we know any class of animals that secrete any much greater quantity of magnesia, as some of the infusorial animals secrete silica. Yet in many widely-spread magnesian limestones the quantity of magnesia is almost equal to that of lime, and the proportion is frequently as much as 20 to 30 per cent. Forchhammer, however, found 2·1 per cent in *Corallium nobile*, 6·36 per cent in *Isis hippuris*, and 7·64 per cent in some species of *Serpula*, while 16 to 19 per cent have been found in some species of *Millepore*.† Magnesian limestones are, however, generally poor in organic remains, though this may be the result of their more perfect crystallisation and mineralisation, by which the organic structure has been obliterated, rather than of the absence of organic beings from the original deposit. Mr. Sterry Hunt has demonstrated the possibility of the chemical deposition of dolomite in isolated lakes or seas, where great evaporation is taking place, but it is difficult to imagine many of our dolomites to have been formed in such situations.

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* Bischof, vol. i. pp. 99 to 105, 117. The quantity of carbonate of magnesia carried down by the Rhine into the sea in the course of twenty-four hours, is 4,621,956 lbs., sufficient to yield 10,087,202 lbs. of dolomite, consisting of equal equivalents of the carbonates of lime and magnesia. This quantity would be equal to a square mass 1 foot high, and 239 feet in the side every day, or 4560 feet in the side in the course of a year.—(Bischof, iii. 178.)

† Mr. Sterry Hunt (*Geol. Reports of Canada* for 1857, p. 208), who cites a dolomite of recent formation at Tahiti, believed by Dana to be formed by the solidification of coral mud (p. 196).

Of the other mineral constituents of sea-water the most important is silica. It was found by Forchhammer in all the specimens of sea-water analysed by him, the greatest proportion being ·03 in 10,000 parts of water. Silver and arsenic have been detected in sea-water; iodine occurs in marine plants, and is probably derived from the water; and the phosphates found in marine animals have probably a similar origin.

The chemical changes effected by the water of the sea upon submarine and shore rocks have not yet been properly studied.*

2. Influence of the Ocean on Climate.

The discussion of this part of the subject belongs more properly to physical geography. It may be enough here to point out that the currents of the globe tend to diffuse temperature: those from a colder region cool the regions into which they pass; while, on the other hand, those from a warmer latitude carry its warmth into colder areas. Thus the Arctic current flowing down along the north-east coast of America reduces the mean annual temperature; while the Gulf-stream, which reaches the shores of the north-west of Europe, raises the temperature. Hence Dublin and the south-eastern headlands of Labrador, which are in the same parallel of latitude, differ as much as 18° in their mean annual temperature, that of Dublin being 50°, and that of Labrador 32° Fahr.†

3. Erosion of the Land by the Sea.

Breaker-Action.—The waters of the sea are kept in constant movement by currents and tides. Wherever this moving water can push forward mud, sand, gravel, or boulders, it effects a mechanical erosion of the rock on which these detrital materials are moved. This action must be very feeble at great depths. It is at its maximum where the surface waters of the sea infringe upon the land.

The force of the breakers of the Atlantic on the west coast of Scotland was found to be on the average equal to a pressure of 611 lbs. on the square foot in summer, and 2086 lbs. in winter. The force of breakers during storms was ascertained, for the Atlantic at Skerryvore, and for the North Sea at the Bell Rock, to be sometimes equivalent to a pressure of nearly three tons per square foot.‡ The immense force of the blow given by one of these breakers must often remove fragments of rock, especially when these have been already loosened by weathering.

But it is when the waves beat on a rocky shore, where they can lift up and hurl forward gravel and blocks of stone, that they attain their highest power as destructive agents. The rocks against which they dash the detritus of the beach are battered down as by a kind of

* See, however, the 7th chapter of the 1st volume of Bischof's work.

† The student may consult with profit some recent papers by Mr. Croll on the "Gulf-stream" and "Ocean Currents," in the *Geol. Mag.* and *Phil. Mag.* for 1869 and 1870.

‡ Stevenson, *Trans. Roy. Soc. Edin.* xvi. 25, 28.

artillery.* Such parts of the cliffs as are softer or more jointed than others, are hollowed out into bays, creeks, and caves, while the more resisting parts stand out as headlands.†

The power of waves to move large blocks of stone is sometimes remarkably displayed during storms. Masses of rock, many tons in weight, are rolled about like pebbles, and even swept away for a considerable distance.

At high-water, and during gales of wind, with heavy breakers rolling in upon the coast, vast volumes of water are poured suddenly into the narrow sea-worn caverns, and rolling on, compress the air at their farther end into every joint and pore of the rock above, and then suddenly receding, suck both air and water back again, with such force as now and then to loosen some part of the roof. Working in this way, the sea sometimes gradually forms a passage for itself to the surface above, and if that be not too lofty, forms a "blow-hole" or "puffing-hole," through which spouts of foam and spray are occasionally ejected high into the air. At the promontory of Loop Head, Mr. Marcus Keane has observed that considerable blocks of rock have been blown into the air on the formation of one of these puffing-holes, and that large holes, opening down into cavernous gullies, lead from one cove to another, behind bold headlands of over a hundred feet in height, showing how the land is undermined by the sea, and headlands gradually made into islands. One such square precipitous island, which is now at least twenty yards from the mainland, was said by the farmer who held the ground to have been accessible by a twelve-foot plank when he was a boy. Mr. W. L. Wilson, late of the Geological Survey of Ireland, found in the far part of the promontory between Bantry and Dunmanus Bays, dark holes in the fields some distance back from the edge of the cliffs, looking down into which the sea might be dimly seen washing backwards and forwards in the narrow cavern below. In County Kerry, Ballybunion Head is completely undermined by caverns, into which the sea enters from both sides. The whole coast of Clare,

* Playfair's *Illustrations*, § 97.

† The nature and extent of the erosive action of the breakers may be partly gathered from a singular anecdote given by Mr. W. J. Henwood in the 5th vol. of the *Trans. Roy. Geol. Soc. Corn.* p. 11. "I was once," he says, "underground in Wheal Cock, near St. Just, during a storm. At the cliff the level was 20 fathoms below high-water, but the ore was worked to within 9 feet of the sea at the time of my visit (1821). At the extremity of the level, seaward, some 80 or 90 fathoms from the shore, little could be heard of the effects of the storm, except at intervals, when the reflux of some unusually large wave projected a pebble outward, bounding and rolling over the rocky bottom. But when standing beneath the base of the cliff, and in that part of the mine where but 9 feet of rock stood between us and the ocean, the heavy roll of the large boulders, the ceaseless grinding of the pebbles, the fierce thundering of the billows, with the crackling and boiling, as they rebounded, placed a tempest in its most appalling form too vividly before me ever to be forgotten."

and of the Aran Islands, is a succession of precipitous cliffs with vertical faces, the result of the sea acting on the large cuboidal joints that traverse the rocks. The celebrated cliffs of Moher in that county, which rise with a perfectly vertical face to heights of more than 600 feet, afford magnificent examples of the way in which the ocean takes advantage of the joint structure to cut back into the land, however lofty or however hard and unyielding it may apparently be.*

The coast-line of Great Britain affords many illustrations of this geological process. Within the last few centuries whole parishes and villages have been washed away, and ships now sail over districts which in old times were cultivated fields and cheerful hamlets. The rate of loss is particularly high along the coast of Yorkshire, between Flamborough Head and the mouth of the Humber, also between the Wash and the mouth of the Thames. The cliffs there consist of soft clay, and in some places are said to be carried away at the rate of three feet per annum.†

As the ceaseless gnawing of the land goes on, the sea gradually advances. The detritus thus formed, while it wears away the cliffs, is itself in turn worn away, and swept by currents into deeper water, or into sheltered parts of the coast. But fresh detritus is always produced as the waste of the land goes on, and becomes the means of renewed destruction.

Sometimes the breakers, after exerting a certain amount of destructive action, seem to raise a rampart against themselves out of the very ruins which they have caused by the fall of the blocks and masses they have undermined; but the materials thus accumulated are themselves then attacked, and ultimately removed, and the coast laid bare for new undermining action. Great accumulations of pebble beaches are common along many coasts, and seem to remain stationary, since there are always piles of pebbles to be found in the same places. If, however, these are watched, the accumulations will often be found to consist of different pebbles from day to day, each pebble being in its turn washed from its place, which is occupied by another like it. The great Chesil Bank, connecting the island of Portland with the mainland, and sixteen miles in length, is a remarkable example, the pebbles in any particular part of it being always much of the same size, but each one travelling gradually onwards, and getting smaller and smaller as it proceeds.‡

* See the late Mr. Foot's account of this coast in Explanation of Sheets 141 and 142 of the Geological Survey of Ireland.

† For instances of the destructive and transporting action of the sea during historic times, see Von Hoff, *Veränderungen der Erdoberfläche*, Theil i. p. 47 *et seq.*; Lyell's *Principles*, chaps. xx., xxi., and xxii.; Stevenson, *Mem. Wernerian Soc.* vol. ii.; De la Beche's *Geological Observer*, p. 53, and *Report on Devon and Cornwall*; Geikie's *Scenery and Geology of Scotland*, chap. iii.

‡ See Bristow and Whitaker, *Geol. Mag.* vi. 433.

Action of Ice on the Sea.—In high latitudes the sea is covered with ice, derived from two sources—1st, from the seaward end of glaciers; 2d, from the freezing of the sea itself. The former source furnishes *icebergs*, the latter gives rise to *floe-ice* and the *ice-foot*.

1. When a glacier descends to the level of the sea and continues to move forward, it may advance for a considerable distance from the shore until the oscillating motion of the tides or the effects of currents and storms break off large masses or *icebergs*. These float away, and, unless caught by the next winter, and frozen into the cake of ice which forms upon the sea, may be carried for hundreds of miles into temperate latitudes before they finally melt away. As a geological agent an iceberg has two chief functions—(1.) To carry away from the land and drop into mid-ocean all the earth and rock-rubbish which may have fallen upon, or become imbedded in, the ice when it formed part of the land-glaciers. The debris of the valleys of Greenland may in this way be scattered far southward over the bed of the Atlantic. (2.) To tear up the softer deposits of the sea-bed, and to rub down and groove the harder rocks, by means either of stones fixed in the ice or of those which may be lying on the sea-bottom. About eight times more ice of an iceberg is below water than above, so that a mass which rises 300 feet above the waves has its bottom 2400 below them. We cannot doubt that the motion of one of these enormous bergs upon or against a submarine rock-surface must grind it and groove it, and that, during a long course of years, any prominent bank or bottom on which the bergs strand, must be greatly abraded.

2. The freezing of the Arctic Sea gives rise to a cake of ice along the shores. This rises with the tide, and freezes to the land again at a higher level. By degrees a shelf of ice 120 or 130 feet broad, and 20 or 30 feet high, called the ice-foot, clings to the coast, and remains there during winter. When spring comes, millions of tons of rock-rubbish, disintegrated and loosened by the winter frosts, fall upon the surface of the ice-foot. Then come the storms by which the ice-foot is broken up, and great cakes of it, dark with their freight of detritus, float away out to the open sea, where in the end they melt, and strew their earth and stones over the bottom. By this means enormous quantities of the debris, so largely produced by the Greenland frosts, are carried away from the land, and the bed of the seas in those regions must consequently in many places be covered with a thick deposit of angular rock-rubbish.*

General result of Sea-action.—The general result of the erosive action of the sea is to cut into the land, and to plane it down to an approximately level surface beneath the waves. Marine denudation,

* See Kane's *Arctic Explorations*, vol. ii., p. 225; Sutherland, *Quart. Journ. Geol. Soc.*, vol. ix. p. 305.

therefore, gives rise to a plane. The subaerial denudation, or the operations of the various agents which are at work on the land, produce inequalities. The one forms the surface of a future table-land, the other scoops out valleys and ravines.

It ought to be borne in mind, however, that the action of the sea is greatly aided by the co-operation of subaerial waste. If there were no frosts, springs, and rain, loosening the framework of a cliff and detaching its fragments to the bottom, the sea would make comparatively slow progress. If the cutting back of a cliff were mainly the work of the sea, we ought to find the cliff overhanging, because the sea acts only at its base. But the fact that in the vast majority of cases, sea-cliffs, instead of overhanging, slope backward, at a greater or less angle from the sea, shows that the waste from subaerial action is really greater than that from the action of the breakers. What the sea chiefly does is to break down and wash away the rubbish which falls from the cliffs, and thus to leave an ever fresh surface for renewed denudation.*

4. The Sea as the receptacle for the debris of the Land.

We have now seen that the surface of the land is undergoing continual waste, and that, although its detritus may be temporarily lodged upon lake-bottoms or alluvial plains, it is nevertheless in the end destined to find its way into the sea. The sea, therefore, receives not merely the detritus which its own tides, waves, and currents may make, but that also which is carried off by rivers, ice-floes, and icebergs, as well as all the mineral substances which rivers hold in solution. All this detritus is spread out over the sea-floor by means of currents. When the sediment is fine, and the current into which it comes is strong, it may be carried hundreds of miles. Even pebbles and gravel may be moved by currents to vast distances from land.

The current that sweeps round the extremity of Africa, from the Indian Ocean to the Atlantic, is at once distinguishable, by its dirty olive-green colour, from the deep blue of the pure ocean water, even in a depth of 100 fathoms, and out of sight of land. Small pebbles have been brought up from that depth by the lead, and the change of colour in the water can hardly be due to any other source than the presence of minutely divided mineral matter held in suspension by the water.†

The sea on the west coasts of Ireland and Scotland, where the current sets upon the land from the Gulf-stream, is the deep clear ocean blue, even in the bays and harbours, and is very different from the dirty green water of the English Channel, the Irish Sea, or the German Ocean, which has become loaded with matter from the washing of our coasts and rivers. This difference may be seen on the small scale in the bays of the western coasts. After a day's storm and rain a margin of green discoloured water may be seen extending some half-mile in width all round the shores, singularly contrasted with the bright blue water of the bay. The boundary between the two kinds of water is often perfectly well defined, so that it can be seen from a boat a quarter of a mile ahead, and the

* See the remarks on this subject by Mr. Whitaker, *Geol. Mag.*, vol. iv.

† *Voyage of H.M.S. Fly.*

moment observed in which the boat passes from one kind of water to the other. The dirty water travels slowly with the receding tide toward the mouth of the inlets, whence it either sinks to the bottom or is swept away by marine currents. This discoloration of the water, then, is due to the washing of the land during heavy rains, proceeding either directly from the cliffs or from the numerous little brooks and rivers.

The materials derived from the land, either by river or sea action, are carried to greater or less distances, according to their fineness. In the Irish Sea, according to the Admiralty charts, sand alone is to be found within some miles of the shore, while, in the central and deeper parts, the bottom is formed of mud. There are two central mud-belts in the northern part, one on each side of the Isle of Man, the one running towards the Solway, and the other continuing into the Clyde mouth. In the English Channel there is nothing to be found but sand, with or without gravel or stones; but opposite to the entrance of the Bristol Channel, and in the deeper water south of Ireland and west of the Scilly Islands, there are large deposits of mud surrounded by sand, the mud continued in narrow arms, which stretch out into the Atlantic, where it apparently blends with ooze that may probably be of organic origin. In the German Ocean, in like manner, mud is found only in the central and deeper parts, between Denmark and the Dogger Bank; and in the mouth of the Baltic, between Denmark and Norway, all the seas within some miles of the shore have a sandy bottom.

If we compare the "bottom," as indicated in the charts of the shores of the North Atlantic, with that of its centre, as shown by the soundings taken for the Atlantic telegraph, we shall find, on the ocean-bottom, one widely-spread uniform deposit of sticky ooze drying into a kind of chalk, with little or no change, over spaces more than 1000 miles across; while the change from this to the sands and muds as we approach the coasts is sudden, and the changes in the nature of the shore deposits are both frequent and rapid.* Yet all these deposits are taking place contemporaneously, and would, if the bed of the Atlantic were elevated into dry land, be almost necessarily grouped together under one name.

In the great Pacific Ocean deposits are taking place, derived from the coral reefs, having a constant character over an area quite as wide as any of the formations we are acquainted with on dry land. This great formation may not be absolutely continuous, even over all that part of the ocean in which the coral reefs occur; but beds of precisely identical mineral character, and containing almost exactly the same organic remains, must be spread over large areas round several central points. Some of these areas of deposition of limestone may overlap each other, while others will be separated by clear spaces of sea-bottom, where probably no deposition is taking place, or by other sea-bottoms, where sediment is deposited of altogether a different character from that derived from the coral reefs. All the great rivers of Eastern Asia, for instance, as well as those of the north-west coast of America, carry down earthy materials into the Pacific, of a totally different character from the coral-reef detritus; and some of this may be very widely spread, and form large deposits on both sides of the Pacific. If fine sediment derived from two such different sources overlap, now one sort and now another being thrown down, with an occasional admixture of both, we should have the contemporaneous formation of one kind of rock in one locality, and another in another, with intermediate areas affording alternations of the two—circumstances which appear to have been of not unfrequent occurrence during the accumulation of great formations composing the existing lands of the globe.

In the China Sea and the northern part of the Indian Ocean, where coral islands are mingled among active volcanoes, both aerial and submarine, and into

* See *ante*, Chapter VI. For descriptions of the organic deposits in the sea, see *ante*, pp. 384-9.

which open the mouths of vast rivers, draining a great continent, many varieties of rock must be in course of production. All these different kinds of rock would enclose the remains of many animals and plants of the same species throughout, or of species so nearly allied as to show that their variations depended chiefly on the geographical distribution of organic beings inhabiting different parts of the globe at the same time. If elevated into dry land, then, they would, by the rule now followed by geologists, be grouped together as one "formation," under some one common designation.

A remarkable case of sudden change in the character of deposits, now being formed side by side, occurs on the north-east coast of Australia, which is fronted by the vast limestone formation known as the Great Barrier coral reef, extending more than 1000 miles in length, and sometimes 90 in breadth. This formation runs across Torres Straits, where it environs some volcanic islands, partly composed of lava, partly of a breccia of fragments of lava and limestone, up to the shores of New Guinea, where it terminates in Warrior's Reef. To the N. and N.E. of that point, however, no coral is to be seen for a space of about 150 miles, the sea-bottom being everywhere formed of black mud and silt, brought down by numerous rivers that are surrounded by mangrove swamps for many miles into the interior. This muddy bottom extends for 60 miles from the shore, but immediately beyond it the coral reefs set in again on the shores of New Guinea, and extend into the Louisiade Archipelago.

The reefs of the Great Barrier are in some places at least 1800 feet thick. What may be the thickness of the mud deposit we have no means of knowing, but we have here as good an instance as could be desired of the sudden replacement of a great limestone formation by one composed wholly of silt, and the setting on of the limestone formation again in an equally sudden manner. There must also be an equally good illustration of the sudden intrusion of igneous rocks, and the interstratification of materials derived from them among the calcareous and other deposits.

The sudden interchanges and replacements among the marine deposits formed near the coast have been already referred to. The coarser sediment, such as shingle and gravel, is laid down nearer the shore, and the finer silt and mud in the deeper water. The coarser the detritus, the more rapidly does it die out and come in again, as is shown by the way in which gravel-banks are formed along shore; while, on the other hand, the finer the silt the farther is it carried, and the wider the area of the deposit which it forms. *

* See *ante*, Chapter VI.

CHAPTER XXV.

DENUDATION.*

DENUDATION consists in the wearing away of rock-masses, and the consequent exposure of other rocks previously covered. It is one of the most important words in the geological vocabulary, for, inasmuch as all sedimentary rocks have been formed out of the detritus of other rocks, denudation is seen to be necessary to, and co-extensive with, deposition. The main mass of what we call the earth's crust is formed of sedimentary rocks, and is therefore one of the results achieved by denudation. But apart from the production of sediment, and ultimately of sedimentary rocks, denudation has had a main share in fashioning the external contour of dry land, from the earliest geological epochs down to our own day. It is impossible to trace the origin of the various forms of mountain and valley, hill and dale, without encountering at every turn proofs of the enormous influence which the denuding forces have exercised upon the earth. A vivid realisation of the nature and results of denudation, therefore, is of the most essential importance to the student of geology. In the foregoing chapters we have passed in review the mode of working which characterises each of the agents concerned in denudation. It will now be of advantage to take a general survey of the process as a whole, without particular reference to the individual agents by which it is carried on. For this purpose we may consider the subject under two aspects—1st, The progress of denudation; and 2d, The results of denudation.

1. THE PROGRESS OF DENUDATION.

A. Subaerial Denudation.

a. Considered as the removal of so much Rock from the General Surface of a Country.

The true measure of the denudation of a country—that is, the extent to which it is now being worn away by the various complicated agencies of waste—is to be sought in the amount of mineral matter removed from the surface of the land and carried into the sea. This

* This chapter is taken mainly from an essay contributed by the Editor to the 3d volume of the *Transactions of the Geological Society of Glasgow*, "On Modern Denudation."

is an appreciable and measurable quantity, and how much soever we may dispute regarding the way in which the waste is to be apportioned to the different forces which have produced it—rain, frost, springs, rivers, glaciers, and the rest—we must accept the total amount of sea-borne detritus as a fact about which, when properly verified, no further question can possibly arise. In this manner the subject is at once disencumbered of all those vexed questions regarding the relative importance of the various denuding agents. We have simply to deal with the sum-total of results achieved by all these forces acting severally and conjointly. In considering the subject in this fashion, we find a new light cast on the origin of existing land-surfaces, and obtain some fresh data for approximating to a measure of past geological time.

Of the mineral substances received by the sea from the land, one portion, and by far the larger, is brought down by streams; the other is washed off by the waves of the sea itself. It is the former, or stream-borne part, which is at present to be considered. The quantity of mineral matter carried every year into the ocean by the rivers of a continent represents the amount by which the general surface of that continent is annually lowered. If, therefore, we can measure the quantity of mineral matter, we may easily calculate by what fraction of a foot the general surface of the land is annually reduced. Much has been written of the vastness of the yearly tribute of silt borne to the ocean by such streams as the Ganges and Mississippi; but "the mere consideration of the number of cubic feet of detritus annually removed from any tract of land by its rivers does not produce so striking an impression upon the mind as the statement of how much the mean surface-level of the district in question would be reduced by such a removal."* This method of inquiry is so obvious and instructive that it probably received attention from early geologists, though data were still wanting for its proper application. Playfair, for instance, in speaking of the transference of material from the surface of the land to the bottom of the sea, remarks that "the time requisite for taking away by waste and erosion two feet from the surface of all our continents and depositing it at the bottom of the sea, cannot be reckoned less than 200 years."† This estimate does not appear to have been based on any actual measurements, and must, as we shall see, greatly exceed the truth; but it serves to indicate how broad was the view which Playfair held of the theory which he undertook to illustrate. The first geologist, so far as I am aware, who attempted to form any

* Tylor, *Phil. Mag.* 4th Series, v. 268 (1850).

† *Illustrations*, p. 424. Manfredi had previously made a calculation of the amount of rain that falls over the globe, and of the quantity of earthy matter carried into the sea by rivers. He estimated that this earthy matter distributed over the sea-bed must raise the level of the latter five inches in 348 years. Von Hoff, *Veränderungen der Erdoberfläche*, Theil i. 232. See the other authorities there cited.

estimate on this subject from actually ascertained data, was Mr. Alfred Tylor, who, in the year 1850, published a paper in which he estimated the probable amount of solid matter annually brought into the ocean by rivers and other agents. From the data which he had obtained, he inferred that the quantity of detritus now distributed over the sea-bottom every year would, at the end of 10,000 years, cause an elevation of the ocean-level to the extent of at least three inches.* Mr. Croll has recently drawn attention afresh to this subject, particularly instancing the Mississippi as a measure of denudation, and thereby of geological time.†

When the annual discharge of mineral matter, carried seaward by a river, and the area of country drained by that river, are both known, the one sum divided by the other gives the amount by which the drainage area has its mean general level reduced in one year. For it is clear that if a river carries so many millions of cubic feet of sediment every year into the sea, the area drained by it must have lost that quantity of solid material; and if we could restore the sediment so as to spread it over the basin, the layer so laid down would represent the fraction of a foot by which the surface of the basin has been lowered during a year. Mr. Tylor has well shown that the process by which such startling results are obtained is a simple arithmetical one. In order, however, to obtain them with complete satisfaction, we must first be furnished with carefully collected and verified measurements, both of the amount of mineral matter carried into the sea by any given river, and of the area of drainage from which that mineral matter is derived. It is to be regretted that, as yet, these measurements have not been generally made with the requisite accuracy. The results at present obtainable from them are therefore necessarily only approximative. Nevertheless, they are of value as indicating the character of the conclusions which must eventually be deduced from more perfect data, and the direction in which research ought in the meantime to be carried.

The material removed from the land by streams is, as we have seen, twofold; one part is chemically dissolved, the other mechanically suspended in the water, or pushed along the bottom by the onward motion of the stream. The chemically dissolved ingredients are derived partly from springs, partly from the flow of rain and streams over decomposing rocks at the surface. The reality and magnitude of this source of waste are apt to escape notice from the quiet and invisible way in which the process is carried on. The published analyses of river-

* *Phil. Mag.*, *loc. cit.*

† *Phil. Mag.* for February 1867 and May 1868. The student will find it of advantage to consult these memoirs, especially the latter, the conclusions in which agree with those given in the present chapter. See *Trans. Geol. Soc. Glasgow*, vol. iii. p. 158—*note.*

water, however, suffice to show its importance. The Thames, for example, carries into the sea every year about 450,000 tons of salts invisibly suspended in its waters. Bischof's calculation regarding the quantity of carbonate of lime, carried annually into the sea by the Rhine, has already been given.*

Properly to estimate the amount of loss sustained by the area which any given river drains, we ought to know the mean annual discharge of river-water, the proportion of saline matter held in chemical solution in the water, the average ratio of mud held in suspension, and of sand and coarser sediment pushed along the channel of the stream. It does not appear that all these data have yet been collected with care from any river, though some of them have been ascertained with great accuracy, as in the Mississippi Survey of Messrs. Humphreys and Abbot. As a rule, more attention has been shown to the amount of mechanically suspended matter than to that of the other ingredients. For the present, therefore, we must confine ourselves to this part of the earthy substances removed from the land by running water. It will be borne in mind that the following estimates, in so far as they are based upon only one portion of the waste of the land, are under-statements of the truth.

The proportion of mineral substances held in suspension in the water of rivers has been variously estimated, but the older calculations, based on mere conjecture, are hardly worth serious consideration. Manfredi, for example, set down the proportion as $\frac{1}{175}$; Maillet, $\frac{1}{1700}$; Hartsoeker, $\frac{1}{100}$; Sir George Staunton, in the case of the Yellow River, $\frac{1}{200}$, and another writer quoted by Von Hoff, $\frac{1}{51080}$.† Some uncertainty arises with regard to the older estimates, whether the figures refer to the proportion of sediment by weight or by bulk. It is most advantageous to determine the amount of mineral matter by weight, and then from its average specific gravity to estimate its bulk as an ingredient in the river-water. The proportion by weight is probably, on an average, about half that by bulk.

According to experiments made upon the water of the Rhone at Lyons, in 1844, the proportion of earthy matter held in suspension was by weight $\frac{1}{17000}$. Earlier in the century the results of similar experiments at Arles gave $\frac{1}{7000}$ as the proportion when the river was low, $\frac{1}{250}$ during floods, and $\frac{1}{2000}$ in the mean state of the river. The greatest recorded quantity is $\frac{1}{25}$ by weight, which was found "when the river was two-thirds up, with a mean velocity of probably about 8 feet per second."‡ Lombardini gives $\frac{1}{300}$ as the proportion by volume of the sediment in the water of the Po. In the Vistula, according to M. Spittell, the proportion by volume reaches a maximum of $\frac{1}{25}$.§ The

* *Ante*, p. 397. † Von Hoff, *Op. cit.* i. 232.

‡ Humphreys and Abbot. Report upon the Physics and Hydraulics of the Mississippi, 1861, p. 147. § *Ibid.* p. 148.

Rhine, according to Hartsoeker, contains $\frac{1}{100}$ by volume as it passes through Holland; while at Bonn, the experiments of the late Mr. Leonard Horner gave a proportion of only $\frac{1}{10000}$ by volume.* Stiefensand found that, after a sudden flooding, the water of the Rhine at Uerdingen contained $\frac{1}{1584}$ by weight. Bischof measured the quantity of sediment in the same river at Bonn during a turbid state of the water, and found the proportion $\frac{1}{4375}$ by weight; while at another time, after several weeks of continuous dry weather, and when the water had become clear and blue, he detected only $\frac{1}{57500}$.† In the Maes, according to the experiments of Chandellon, the maximum of sediment in suspension in the month of December 1849 was $\frac{1}{3100}$, the minimum $\frac{1}{71430}$, and the mean $\frac{1}{10000}$.‡ In the Elbe, at Hamburg, the proportion of mineral matter in suspension and solution has been found by experiment to average about $\frac{1}{7400}$. The Danube, at Vienna, yielded to Bischof about $\frac{1}{4300}$ of suspended and dissolved matter.§ The Durance, in floods, contains $\frac{1}{48}$ of suspended mud, and its annual average proportion is less than $\frac{1}{1000}$.|| The Garonne is estimated to contain perhaps $\frac{1}{100}$.¶

The observations of Mr. Everest upon the water of the Ganges show that, during the four months of flood in that river, the proportion of earthy matter is $\frac{1}{428}$ by weight, or $\frac{1}{856}$ by volume; and that the mean average for the year is $\frac{1}{510}$ by weight, or $\frac{1}{1031}$ by volume.**

But by far the most extensive and accurate determinations upon this subject yet made, are probably those of Messrs. Humphreys and Abbot, who were employed by the United States Government to report upon the physics and hydraulics of the Mississippi river. The voluminous memoir which these observers have produced may be taken as a model of patient and exhaustive research. As the mean of many observations carried on continuously at different parts of the river for months together, they found that the average proportion of sediment contained in the water of the Mississippi is $\frac{1}{1500}$ by weight, or $\frac{1}{2900}$ by volume.†† But besides the matter held in suspension, they observed that a large amount of coarse detritus is constantly being pushed along the bottom of the river. They estimated that this moving stratum carries every year into the Gulf of Mexico about 750,000,000 cubic feet of sand, earth, and gravel. Their observations led them to conclude that the annual discharge of water by the Mississippi is 19,500,000,000,000 cubic feet, and, consequently, that the weight of mud annually carried into the sea by this river must

* *Edin. New Phil. Jour.*, xviii. p. 102. † See his *Chemical Geology*, i. 122.

‡ *Annales des Travaux Publics de Belgique*, tome ix. 204. § *Op. cit.* 130.

|| Payen, cited by E. Réclus. *La Terre*, tome i. p. 537.

¶ Baumgarten, cited by Réclus, *Op. cit.—Ibid.*

** *Jour. Asiatic Society of Calcutta*, March 1832.

†† Report, p. 148. The specific gravity of the silt of the Mississippi is given as 1·9.

reach the sum of 812,500,000,000 pounds. Taking the total annual contributions of earthy matter, whether in suspension or moving along the bottom, they found them to equal a prism 268 feet in height with a base of one square mile.

It is much to be desired that careful measurements should be made of the quantity of silt carried down annually by our British rivers. The amount which is deposited in harbours at river mouths has indeed been in many cases measured.* But this can of course afford but a vague measurement of the total amount which is brought down from the land and carried out to sea. In the case of the river Nith, a series of measurements and deductions, made by the resident engineer, led him to the conclusion that the quantity of detritus borne by that stream into the Solway Firth reaches every year the amount of from 112,000 to 120,000 cubic yards.†

No one can have witnessed the effects of a violent or long-continued fall of rain upon even the small streams in the hilly parts of this country without being impressed with the amount of waste which the surface of the land is continually suffering from this cause. At Inverness, for example, the burn of Holm, during a "spate," sometimes carries down several thousand tons of stones and gravel into the river Ness.‡ Mr. Thomas Stevenson, the eminent harbour engineer, informs me that at Lybster, on the Caithness coast, where a harbour has been constructed at the mouth of a small stream, between 400 and 500 cubic yards of gravel and sand are every year carried down by the stream. A weir or dam has been constructed to protect the harbour from the inroad of the coarser sediment, and this is cleaned out regularly every summer. But by far the greater portion of the fine silt is no doubt swept out into the North Sea. The erection of the artificial barrier, by arresting the seaward course of the gravel, reveals to us what must be the normal state of this stream, and of all similar streams descending from maritime hills.§ Over and above the quantity of fine silt, the presence of which is abundantly manifest in the turbid colour of the water during a rainy season, there are annually carried along the bottom of the channel, and thence into the sea, enormous quantities of coarser sediment. Even when this under stratum of moving gravel cannot be seen under the discoloured water, the stones of which it is composed may be heard knocking against each other as the current sweeps them onward. I was much struck with observing this on the

* See the evidence on this subject collected in Appendix C to *Tidal Harbours Commission*, 1847. In Dundee Harbour the deposit of silt is said to amount to two or three feet in a year. Six inches of deposit annually appears to be a common quantity.

† *Op. cit.* p. 603. ‡ *Op. cit.* p. 348.

§ The area drained by this stream is about four square miles; consequently the amount of loss of surface which is represented by the coarse gravel and sand alone is $\frac{1}{1500}$ of a foot.

Rhine and Moselle. Above Bonn, and again a little below the Lurelei Rock, while drifting down the former river, I could, by laying my ear close to the bottom of the open boat, hear the harsh grating of the gravel stones over each other as the current kept pushing them onwards along the bottom. The water was rather low, but the current remained tolerably swift. Again, on the Moselle, between Cochem and Coblentz, I observed the same fact. From these observations, it is evident that the quantity of material held in suspension by no means represents all the detritus removed by a river from the area which it drains.

It may seem superfluous to insist that the earthy matter borne into the sea from any given area represents so much actual loss from the surface of that area. Yet this self-evident statement is probably not realised by many geologists to the extent which it deserves. If a stream removes in one year one million of cubic yards of earth from its drainage basin, that basin must have lost one million of cubic yards from its surface. We are not now to consider whether the loss has been borne equally by the whole surface, or falls only on special parts of it: this part of the subject will be reverted to in the sequel. It is sufficient for the present to regard the loss as a reality, which we see daily before our eyes, and which we can approximately measure.

From the data and authorities which have now been adduced, the subjoined table has been constructed, in which are given the results of the measurement of the proportion of sediment in a few rivers. The last two columns show the fraction of a foot, which each river must remove from the general surface of its drainage basin in one year. In the first of these two columns the sum represents the loss in sediment; and allowing the average specific gravity of river-silt to be 1·9, and that of rocks to be 2·5, the second column shows the amount of solid rock which must annually be removed.

Name of River.	Area of basin in square miles.	Annual discharge of Sediment in cubic feet.	Proportion of Sediment in water.		Fraction of foot by which the area of drainage is lowered in one Year.	
			By weight.	By volume.	In sediment.	In rock
Mississippi .	1,147,000	7,459,267,200	$\frac{1}{1500}$	$\frac{1}{2900}$	$\frac{1}{4566}$	$\frac{1}{6000}$
Ganges . .	432,480	6,368,077,440	$\frac{1}{510}$	$\frac{1}{1051}$	...	$\frac{1}{2358}$
Hoang Ho .	700,000	17,520,000,000(?)	...	...	...	$\frac{1}{1464}$
Rhone . .	25,000	600,381,800	...	...	$\frac{1}{1161}$	$\frac{1}{1528}$
Danube . .	234,000	1,253,738,600	...	...	$\frac{1}{5909}$	$\frac{1}{6846}$
Po . . .	30,000	1,510,137,000	...	...	$\frac{1}{566}$	$\frac{1}{729}$
Nith . . .	400	1,008,000 to 1,080,000	1 lb. in 32 cubic feet of water.		$\frac{1}{3590}$	$\frac{1}{4723}$

It will be seen that the amount is in some cases nearly ten times greater than in others. In the Po, for example, the rate of waste is more than nine times more rapid than it is in the Danube. The Mississippi rate is only about one-third of that of the Rhone.

At the present rate of erosion, the rivers named in this table remove one foot of rock from the general surface of their basins in the following ratio :—

The	Mississippi	removes	one foot in	6000	years.
„	Ganges	„	„	2358	„
„	Hoang Ho	„	„	1464	„
„	Rhone	„	„	1528	„
„	Danube	„	„	6846	„
„	Po	„	„	729	„
„	Nith	„	„	4723	„

The Mississippi, therefore, is lowering the surface of the great basin which it drains at the rate of one foot in 6000 years. If this rate continues, 10 feet will of course be removed in 60,000 years; 100 feet in 600,000 years; 1000 feet in 6,000,000. The mean height of the North American Continent, according to Humboldt, is 1496 feet.* Under the Mississippi rate of denudation, therefore, that continent would be worn away in about nine million years.

The Ganges works still more rapidly. It removes one foot of rock in 2358 years, and if Humboldt's estimate of the average height of the Asiatic continent be accepted—viz. 2264 English feet,† that mass of land, worn down at the rate at which the Ganges destroys it, would disappear in little more than five millions of years.

Still more remarkable is the extent to which the river Po denudes its area of drainage. Even though measurements had not been made of the ratio of sediment contained in its water, we should be prepared to find that proportion a remarkably large one, if we look at the enormous changes which, within historic times, have been made by the alluvial accumulations of this river. According to the data already cited, the Po removes one foot of rock from its drainage basin in 729 years. This is equal to the removal of ten feet in 7290 years, 100 in 72,900 years. The mean height of Europe is stated to be 1342 English feet.‡ If the whole of that continent were denuded at the same rate as in the basin of the Po, it would be levelled in rather less than a million years.

Although, in the present imperfection of our data, these results cannot be regarded as strictly accurate; yet, on the other hand, they

* *Asie Centrale*, tome i. 168. He gives 748 feet as the height of the mean centre of gravity of the North American continent; 671 feet as the height of the same line for Europe; and 1132 feet for Asia. But there is reason to believe that these estimates are somewhat too high.

† Humboldt, *ibid.*

‡ Humboldt, *ibid.*

are not mere guesses. The amount of water flowing into the sea, and the annual discharge of sediment, have been in each case measured with greater or less precision. The areas of drainage may perhaps require to be increased or lessened. But though some change may be made upon the ultimate results just given, it is hardly possible to consider them attentively without being forced to ask whether those enormous periods which geologists are in the habit of demanding for the accomplishment of geological phenomena, and more especially for the very phenomena of denudation, are not in reality far too vast. If the Mississippi is carrying on the process of denudation so fast that at the same rate the whole of North America will be levelled in nine millions of years, surely it is most unphilosophical to demand unlimited ages for similar but often much less extensive denudations in the geological past. Moreover, that rate of erosion appears on the whole to be rather below the average in point of rapidity. The Po, for instance, works more than eight times as fast. But as the physics of the Mississippi have been more carefully studied than those of perhaps any other river, we shall probably not exaggerate the result if we assume the Mississippi ratios as the average. It may not be without advantage to apply this average to the case of a number of British rivers, the drainage-area and water-discharge of which are known. The subjoined table shows the ascertained amount of water discharged by five rivers in this country. Assuming the proportion of sediment to be the same as in the Mississippi, we obtain the result in the last two columns :—

Name of River.	Area of Drainage.	Annual discharge of Water.	Annual discharge of Sediment.	Fraction of a foot of rock by which the basin is annually lowered.
	Sq. Miles.	Cubic Feet.	Cubic Feet.	
Tay . . .	2,500	144,020,000,000	49,660,000	$\frac{1}{1863}$
Thames . .	5,162	54,111,200,000	1,865,903	$\frac{1}{10166}$
Forth . .	450	15,450,000,000	5,328,000	$\frac{1}{2313}$
Clyde . .	1,580	25,228,000,000	8,699,000	$\frac{1}{6033}$
Boyne . .	700	94,614,000,000	32,622,000	$\frac{1}{7866}$

Hence it appears that if the proportion of earthy matter in the water of the Tay resembles that in the water of the Mississippi, the area of the Highlands, drained by the former river, must be suffering a loss at the rate of one foot in less than 2000 years. This is possibly not an exaggeration, for we have already seen that, disregarding the finer silt carried off in suspension, the amount of gravel and sand brought down annually by the Nith is equal to a loss of one foot in 4700 years.

There is another point of view from which a geologist may advantageously contemplate the active denudation of a country. He may estimate the annual rainfall and the proportion of water which returns to the sea. If he can obtain a probable average ratio for the earthy substances contained in the river-water which enters the sea, he will be able to estimate the mean amount of loss sustained by the whole country. Thus, if he takes the average rainfall of the British Islands at 36 inches annually, and the superficial area over which this rain is discharged at 120,000 square miles, then it will be found that the total quantity of rain received in one year by the British Isles is equal to about 68 cubic miles of water. Estimates have varied as to the proportion of the rainfall which is eventually returned to the sea by streams. Some writers have given it as probably about a third, others as a fourth.* If we take it at the former estimate, there are 23 cubic miles, if at the latter, there are 17 cubic miles of fresh water sent off the surface of the British Islands into the sea in one year.

When the rain falls it is nearly pure water, but when, after a devious course of sometimes hundreds of miles, it is poured into the sea, it is, as we know, largely charged with mineral matter both in solution and suspension, as well as in motion along the channels of the streams. Let us take some average ratio for these impurities; and we shall probably guard against exaggeration by assuming this ratio to be only $\frac{1}{5000}$ by volume of the water, and the proportion of the rainfall returned to the sea to be $\frac{1}{4}$. At this rate $\frac{1}{8800}$ of a foot of rock must be removed from the general surface of our country every year. One foot will be planed away in 8800 years. The mean height of the British Islands is probably less than 650 feet. Under the existing state of things, therefore, if the ratio now assumed is near the truth, these islands will be levelled in about five and a half millions of years. We still require much more detailed observation in this country before any estimate of this kind can be based upon accurate and reliable data. But I have thought it desirable to indicate it as a method of vividly bringing before the mind the reality and extent of the denudation now in progress.

β. Subaerial Denudation considered as the unequal lowering of the General Surface of a Country.

It is important to regard the annual discharge of sediment from the surface of a country, as a definite quantity which may be measured, and which, when so measured, gives us the amount of loss which that surface has sustained in one year, or, in other words, the extent to which

* Mariotte estimated the proportion of the rainfall discharged by the Seine from its catchment basin as $\frac{1}{6}$; Dausse subsequently made a fresh calculation, and set the proportion at $\frac{1}{3}$.—See Becquerel, *Eléments de Physique Terrestre*, p. 283.

the average level of the country has been reduced. By looking at the subject from this point of view, we obtain some adequate idea of the extent of the loss which the land is constantly undergoing from subaerial causes even before our eyes. At the same time it is sufficiently obvious that the earthy matter annually removed from the surface of the land does not come equally from the whole surface. The determination of the total quantity of earthy materials removed does not assist us in any way to apportion the loss, or to ascertain how much each part of the surface has contributed to the total amount of sediment. On plains, watersheds, and more or less level ground, the proportion of loss may be small, while on slopes and in valleys it may be great, and it may not be easy to determine the true ratios in these cases. *But our estimates and measurements of the sum total of denudation are not thereby affected.* This must not be overlooked. If we allow too little for the loss from the surface of the table-lands, we increase the proportion of the loss sustained by the sides and bottoms of the valleys, and *vice versa.* These proportions must vary indefinitely with the form of the surface, rainfall, etc. But the fact remains, that the balance of loss must always be, on the whole, on the side of the sloping surfaces. In order to show the full import of this part of the subject, I will assume certain ratios, which are probably understatements rather than exaggerations.

Let us take the proportion between the extent of the plains and table-lands of a country, and the area of its valleys, to be as nine to one; in other words, that of the whole surface of the country, one-tenth part is occupied by the valleys, while the remaining nine-tenths consist of broad undulating plains, watersheds, or other comparatively level ground. Let it be further assumed that the erosion of the surface is nine times greater over the latter than over the former area, so that, while the more level parts of the country have been lowered one foot, the valleys have lost nine feet. According to the calculations already given, it appears that the mean annual quantity of detritus carried to the sea, may, with some probability, be regarded as equal to the yearly loss of $\frac{1}{6000}$ of a foot of rock from the general surface of the country. Apportioning this loss over the surface in the ratio just given, we find that it amounts to $\frac{5}{9}$ of a foot from the more level grounds in 6000 years, and 5 feet from the valleys in the same space of time. Then, if $\frac{5}{9}$ of a foot be removed from the level grounds in 6000 years, 1 foot will be removed in 10,800 years; and if 5 feet be worn out of the valleys in 6000 years, 1 foot will be worn out in 1200 years. This is equal to a loss of only $\frac{1}{12}$ of an inch from the table-land in 75 years, while the same amount is excavated from the valleys in $8\frac{1}{3}$ years.

It may seem at first sight that such a loss as only a single line from the surface of the open country during more than the lapse of a long human life is almost too trifling to be taken into account, as it is

certainly too small to be generally appreciable, or even to be easily detected by careful measurements. In the same way, if we are told that the constant wear and tear which is going on before our eyes in valleys and watercourses does not effect more than the removal of one line of rock in eight and a half years, we may naturally enough regard such a statement as probably an under-estimate. But if we only permit the multiplying power of time to come into play, the full force of these seemingly insignificant quantities is soon made apparent. For we find, by a simple piece of arithmetic, that, at the rate of denudation which has been just postulated as probably a fair average, a valley 1000 feet deep may be excavated in 1,200,000 years, a period which, in the eyes of most geologists, will seem short indeed.

The ratios from which this average rate of denudation is computed are framed according to the most probable estimates at present available. They may be replaced by others when more accurate data have been obtained. But it may be again pointed out that, let us assume any other apportioning of the total amount of denudation, we do not thereby lessen the measurement of that amount which can be, and has been, ascertained in the annual discharge of rivers. We have a certain determined quantity of rock annually worn off the surface of the land. If, as already remarked, we represent too large a proportion as derived from the valleys and watercourses, we diminish the loss from the open country; or if we make the contingent derived from the latter too great, we lessen that from the former. Under any ascertained or assumed proportion the facts remain, that the land loses a certain ascertainable fraction of a foot from its general surface per annum, and that the loss from the valleys and watercourses is much larger than that fraction, while the loss from the level grounds is much less.

Objections are sometimes urged against the efficacy of subaerial denudation, on the ground that certain features of the land-surface, which, it is assumed, ought to be rapidly destroyed, nevertheless remain unchanged for centuries. In one sense, it is sufficient reply to point to the clear undeniable fact that every stream annually removes from the land a certain measurable quantity of detritus worn off the surface of the land. To deny that the surface of a country is annually suffering a lowering of its general level from denudation, is to shut the eye to the evidence vividly displayed by every brook and river by which the surface of that country is traversed. Some objectors, however, do not deny the annual loss of rock, but maintain that it is not derived from the general surface of the country, but only from comparatively limited portions, and they point to certain features of the surface as affording proofs of permanence. The most ingenious objections of this kind, which I have yet met with, are stated by M. Elie de Beaumont.* I

* *Leçons de Géologie Pratique*, 1843, tome i. p. 135 *et seq.*

shall give here a sketch of the argument by which the distinguished French geologist endeavours to show that the influence of atmospheric causes is quite insignificant.

The solid rocks are usually more or less covered with a layer of vegetable soil, which, though at first sight it may seem to present few points of interest, dates in reality from a high antiquity, and merits the special study of the geologist. It is intimately associated with human history, and offers in consequence materials for the establishment of positive data in geology. The human monuments which it contains furnish most important geological evidence, for if the inscriptions graven upon them a thousand or two thousand years ago remain still fresh, it is thereby shown that certain parts of the earth's surface may be preserved unchanged for a long time. But apart from the question of their own conservation, these monuments prove that the surface of the ground and the vegetable soil undergo very little modification. The Roman bridges still span the watercourses over which they were built, for the waters have not risen any nearer to the tops of the arches, nor sunk so as to expose the foundations, but pass to-day just at the height for which the bridges were constructed. Hence, the bed of these rivers has not changed. Along different parts of the lower course of the Rhone the Roman remains of different kinds are in perfect accordance with the existing level of the river, and the present régime of that stream appears thus to have remained as it is from time immemorial. A like inference is to be drawn from the occurrence of the large standing-stones so abundant in Europe. These monuments, most of which must be at least 2000 years old, have been simply planted in the soil. If the surface of the soil had been lowered, their base would have been laid bare, had it been raised, their base would have been covered up. But they remain just sunk so far in the soil as to prevent them from falling. This holds true, not only for those on flat ground, but also for those which stand on sloping declivities, and even when in such circumstances they are exposed to all the changes of a maritime climate. Farther, and still more unexceptionable proof of the insignificance of the degradation undergone by grass-covered soil, is found in those ancient earthen mounds, such as tumuli, forts, and camps, which, even with sloping sides, have retained almost perfectly their original forms. The angle of declivity of the ramparts remains what it evidently was at first, and the ditches between the ramparts have not been filled up. Again, in ground which has long been abandoned by the plough, the parallel furrows may still be traced. In Brittany and in Spain, for instance, there are districts where the soil has not been cultivated for a great many centuries, yet where the old ridges made by the plough remain perfectly distinct under the coating of turf. If we watch the influence of sun and rain upon ploughed land, we observe that while the soil is bare these external agents act with comparative rapidity in reducing its surface to a more stable contour, which gets covered with herbage and remains almost without change for an immense period. In this process the action of the atmospheric forces is greater the first year than the second, greater the second year than the third, greater the third year than the fourth, the changes decreasing almost in a geometrical progression. If the effect produced in the second year were half of that in the first, if that produced in the third year were half of that in the second, and so on, the sum-total of change produced at the end of an indefinite time would only be double that effected at the end of the first year. If the second year's alteration were equal to three-fourths of that of the first year, the result at the end of an indefinite period would only be four times that of the first year. Or lastly, if the second year's alteration were nine-tenths of the first year's, the result after an indefinite time would be merely ten times that of the first year.

M. Elie de Beaumont then proceeds to discuss the evidence afforded by vegetation. He contends that, as a tree cannot live unless the soil on which it grows

remains beneath it, so trees which have been several centuries in existence show that the soil during that period has undergone no appreciable change. Even on slopes where the vegetable soil is very thin, there are forests of century-old trees, so that the permanence of the existing surface is thus established for inclined as well as for flat ground. From this point of view the longevity of certain trees acquires a special interest to the geologist, and the author cites a number of examples in illustration. Nor is it merely the higher forms of vegetation that are appealed to. Certain lichens coating the surfaces of rocks may be, to use the words of De Candolle, "as old as the last cataclysm." Grass likewise protects the soil on which it grows, and may be very old. Vegetation generally tends to preserve the present form of the surface, and where it has been removed by man, the soil underneath has in many places been carried away by running water, and the ground rendered for a long while uncultivable. The natural state of the surface of the globe is to be covered and protected by a coating of vegetation. There are, indeed, many places where that surface is subject to continual and very visible degradation, such as the sea-margin and the channels of streams, where the ground is being perpetually, as it were, cut to the quick. But these changes are so perceptible, precisely because in most places the vegetable soil remains nearly unaltered during the lapse of immense periods. This layer of vegetable soil, therefore, is in fact a kind of fixed point or zero by which to measure the phenomena that take place more rapidly.

In introducing the subject, M. Elie de Beaumont remarks that it possesses for the general public the recommendation of requiring no previous geological knowledge. Assuredly, a reader who has no pretensions to science may yet readily detect the fallacy which runs through the whole of the interesting argument of the French savan. The monuments of antiquity on which that argument is founded form but a small fraction of the number of monuments originally constructed. Every year is thinning them down still more, whether it be by the hand of man or by the inevitable march of decay. Destruction is the rule, preservation is the exception. To select, therefore, the examples which, owing to more favourable circumstances, have been preserved, and to take no note of the far greater number which have been destroyed, necessarily leads to a result which is far from being true. Reduced to a syllogism, the argument would be stated thus:—If atmospheric waste could produce during 2000 years any appreciable change upon the surface of a country, human monuments would show it. Some human monuments cited by M. de Beaumont do not show it, therefore atmospheric waste is not productive of any sensible alteration of the surface of a country.

It is not necessary to enter into the details of the reasoning, otherwise it would not be difficult to show that the preservation of old forts and tumuli is in thousands of cases by no means so perfect as is alleged; that the standing-stones which are still erect do not furnish any proof that the soil around them has undergone no change—a statement, indeed, which seems sufficiently negatived by the number of stones lying prostrate; and that for one legible inscription more than two or three centuries old, it would be easy to furnish scores which have been obliterated after a few generations. But even if all these assertions were just, and if it could be conclusively proved that for a thousand or two thousand years certain human monuments had undergone no appreciable alteration, would the inference necessarily be just that, therefore, rain, frost, streams, and the other meteoric agents of decay exercise no material influence upon the general surface of the earth? Is it not manifest that the time during which observations have been made is infinitely too brief to warrant any such sweeping deduction? A process which, in two thousand years, has not effected any perceptible alteration on certain parts of the earth's surface, may yet have been rapid enough in the course of the geological ages, to have worked the most stupendous changes upon that surface as a whole. If, following up the foregoing estimates, we put down the amount of

rock removed annually from the open country as $\frac{1}{10000}$ of a foot, this would amount to no more than 2·22 inches in 2000 years—the time comprised by the evidence of M. E. de Beaumont. This would be a quantity so small as to be wholly inappreciable. Again, if, using still the same estimate, we take the loss of surface from the valleys and water-courses as $\frac{1}{1200}$ of a foot in one year, this would give us only twenty inches in 2000 years—an amount which, in default of any trustworthy standard of measurement, would likewise be inappreciable.*

To these arguments of M. E. de Beaumont may be added another, based on the same kind of reasoning, and which appears to have great weight in the eyes of some geologists—viz. that the ruts, grooves, and scratches, graven upon rocks during the glacial period, remain still fresh, although the surfaces so marked have been opposed to all the vicissitudes of a changeable climate. It is contended that, had atmospheric waste been so powerful as the followers of Hutton maintain it to be, these markings would certainly have been effaced during the lapse of the thousands of years since the ice left them upon the rocks. And the fact of their preservation is pointed to as a proof, that even in a stormy region like that of the western and northern portions of the British Islands, the general surface of the country has remained for thousands of years without appreciable change.

To an eye trained in tracing the effects of ice-action, the general surface of the British Islands wears an unmistakable ice-smoothed aspect. But the localities where the actual ice-polish and striæ are now exposed are few, indeed, when compared with the area from which these fine markings have been effaced, yet which still retain abundant evidence of having once been glaciated. We see the surface in all stages of decay, from rocks where, save perhaps on the large scale, all vestige of ice-action has disappeared, to polished and striated surfaces which remain still fresh. In very many cases where these markings retain such freshness, it is easy to see that they have, till comparatively recently, been protected under a covering of soil, turf, gravel, or clay. In cases where the striated faces of rock have been laid bare by human agency, a few years sometimes suffice to remove the sharpness which they had when the protecting clay was removed from them. Those, for example, who remember the appearance of the striated dolerite on the Queen's Drive at Edinburgh, when that road was made about a quarter of a century ago, will find that even this brief exposure has been enough to remove the original delicacy of the lines. In the old glacier districts of the Highlands, too, I have often noticed well-marked *roches moutonnées*, where the rounded form and the parallel grooves and striæ still remained wonderfully distinct. Yet, on examining these bosses of gneiss or schist, I found that the quartz-veins traversing the rock sometimes projected from the general surface a twelfth of an inch or more, and retained the finer striæ, which were all obliterated from the rest of the rock. Yet, looking at these *roches moutonnées*, one might have been disposed to say that they still remained very much as the ice had left them. Nevertheless, there was here

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* The view taken of this matter by the early leaders of the Huttonian philosophy was as original as it was far-sighted. Playfair concludes his reasoning thus:—"The soil, therefore, is continually diminished, its parts being transported from higher to lower levels, and finally delivered into the sea. But it is a fact that the soil, notwithstanding, remains the same in quantity, or at least nearly the same, and must have done so ever since the earth was the receptacle of animal or vegetable life. The soil, therefore, is augmented from other causes, just as much, at an average, as it is diminished by that now mentioned: and this augmentation evidently can proceed from nothing but the constant and slow disintegration of the rocks. *In the permanence, therefore, of a coat of vegetable mould on the surface of the earth, we have a demonstrative proof of the continual destruction of the rocks;* and cannot but admire the skill with which the powers of the many chemical and mechanical agents employed in this complicated work are so adjusted as to make the supply and waste of the soil exactly equal to one another."—*Illustrations*, p. 106.

proof, that while the general ice-worn character of the rock-surface remained still remarkably distinct, one line or more had been gradually eaten away from that surface. A tolerably wide experience of ice-worn rocks in this country, in Norway, in Switzerland, and among the Eastern Alps, has taught me that glaciated surfaces are no exceptions to the general law of decay, and that as soon as they are directly exposed to the atmosphere, they begin to weather, as all other surfaces do.*

In considering an objection of this kind, we must not forget that of all possible forms of surface, that of an ice-smoothed boss or face of rock is probably the one where the subaerial agencies of waste will have least facility for action, and which will therefore longest retain its contour. The polished surface allows rain to run off at once, and the joints which would otherwise permit the disruptive action of frost are for a long while concealed. The sides of a polished granite obelisk will resist the weather far longer than the surface of a rough block of the same stone. Those, therefore, who employ ice-worn surfaces as evidence against the potency of atmospheric denudation, argue in precisely the same way as M. E. de Beaumont. It is as if they found in a mediæval building the hard well-chiselled corner-stones still retaining the tool-marks, and concluded therefrom that the intervening centuries had produced no change upon the exterior of the walls. Yet, a little further inspection would show that the tool-marks were only visible on the corner-stones, where the hardest freestone had been selected, while the rest of the wall, constructed of less carefully chosen materials, showed in many places courses of stone wholly rotted out, crumbling mortar, and general decay.

γ. Subaerial Denudation as affected by Subterranean Movements of Upheaval or Depression.

The rate at which the various denuding agents have worked would often be affected in past time by elevation or depression of the land. An increase in the mean height of any mass of land would, in most cases, augment the annual fall of rain or snow, and likewise the slope of the rivers descending from the area of greatest elevation. There would then be more rain to wash the country, and the rivers, by their increased velocity, would have an augmented erosive power. Upheaval, therefore, is favourable to subaerial denudation.

On the other hand, when the general level of a mass of land is lowered, the annual precipitation upon its surface tends to decrease. There are less rain and smaller streams to act, and the potency of their action is lessened by the diminished slope over which they flow. Depression, therefore, is thus, on the whole, unfavourable to subaerial denudation.

B. Marine Denudation.

In what has now been considered we have had regard only to that portion of the annual loss of land which is evinced by the transport of mineral substances by rivers into the sea. But besides this portion,

* I have, on a former occasion, called attention to the remarkable and increasing freshness of the ice-markings as we approach the present sea-margin, more particularly among the western sea-lochs of this country. (*Trans. Geol. Soc. Glasgow*, i. part 2, p. 170—*note*. See also my *Scenery of Scotland*, p. 228.) I regard this fact as only explicable on the admission that the maritime *roches moutonnées* have been for but a comparatively brie period exposed directly to the atmosphere.

there is likewise removed, every year, a considerable amount of material by the waves that beat along the margin of the land. We find that even the most iron-bound shores yield to the ceaseless grinding of the breakers. The denudation is often more marked along the coast-line than it is inland, and thus we are apt to take for granted that the sea is much the most powerful agent of destruction, and that marine denudation is the most important of all the various modes in which the bulk of the solid land is from year to year reduced. Such an inference is but natural in a country like our own. Here, islanders as we are, and familiar from infancy with the fury of the breakers which beat along our coast-line, and strew it with wrecks, we are prone to attribute to the ocean the chief share of the work of wearing down the land. Yet, if we attentively consider the abrasion due directly to marine action, we are led to perceive that its extent is comparatively small. In what is called marine denudation, as has already been pointed out, the part played by the sea is mainly that of removing what has already been loosened and decomposed by atmospheric agents. When these decayed portions are carried away, a fresh surface is again laid open to subaerial influences, to be in turn reduced to fragments, and borne away seawards. Were it not, therefore, for the aid given by rains, springs, frosts, etc., the progress of the waves would be comparatively slow. Yet, let us grant to the action of waves and tides all that is usually included under the term *Marine Denudation*, we shall still find that the sum total of waste along the margin of the land must be trifling compared with that which is produced by the meteoric agents upon the interior.

At the outset, it is evident that the extent of surface exposed to the power of the waves is very small indeed when contrasted with that which is under the influence of atmospheric waste. Even in an island like Britain, the discrepancy is great, and, of course, in the case of the continents, it is infinitely greater. In the general degradation of the land this is an advantage in favour of the subaerial agents, which would not be counterbalanced unless the rate of waste by the sea were many thousands or millions of times greater than that of rains, frosts, and streams. But, in reality, no such compensation exists. In order to see this, it is only necessary to place side by side measurements of the amount of work actually performed by the two classes of agents. Let us suppose, for instance, that the sea eats away a continent at the rate of ten feet in a century—an estimate which probably attributes to the waves a much higher rate of erosion than can, as the average, be claimed for them.* Then a slice of about a mile in breadth will

* It may be objected that this rate is far below that of parts of the east coast of England, where the land sometimes loses three or four yards in one year. But, on the other hand, along the rocky western coast, the loss is probably not so much as one foot in a century.

require about 52,800 years for its demolition, ten miles will be eaten away in 528,000 years, one hundred miles in 5,280,000 years. Now we have already seen that, on a moderate computation, the land loses about a foot from its general surface in 6000 years, and that at this rate of subaerial denudation, the continent of Europe would be worn away in about 8,000,000 years. Hence, before the sea, advancing at the rate of ten feet in a century, could pare off more than a mere marginal strip of land, about 150 miles in breadth, the whole land would be washed into the ocean by atmospheric denudation.*

Influence of upheaval and depression.—Such results as these would necessarily be produced if no disturbance took place in the relative levels of sea and land. But in estimating the amount of influence to be attributed to each of the denuding agents in past times, we require to take into account the complicated effects which would arise from the upheaval or depression of the earth's crust. If frequent risings of the land or elevations of the sea-floor into land had not taken place in the geological past, there could have been no great thickness of stratified rocks formed, for the first continents must soon have been washed away. But the great depth of the stratified part of the earth's crust, and the abundant breaks and unconformities among these sedimentary masses, show how constantly the waste of the land was compensated by the result of elevatory movements.

When a mass of land is raised to a higher level above the sea, a larger surface is exposed to denudation. We have already seen that, as a rule, a greater rainfall is the result, and consequently also a more active waste of the surface by subaerial agents. It is true that a greater extent of coast-line is likewise exposed to the action of the waves, but a little reflection will show that this increase will not, on the whole, bring with it a proportionate increase in the amount of marine denudation. For, as the land rises, the cliffs are removed from the reach of the breakers, and a more sloping beach is produced on which the sea cannot act with the same potency as when it beats against a cliff-line. Moreover, as the sea-floor approaches nearer to the surface of the water, it is the former detritus, washed off the land and deposited under the sea, which comes within the reach of the currents and waves. This serves, in some measure, as a protection to the solid rock below, and must be cut away by the ocean before that rock can be exposed anew. While, therefore, elevatory movements tend on the whole to accelerate the action of subaerial denudation, they serve to check the natural and ordinary influence of the sea in wasting the land. Again, the influence of movements of depression will probably be found to tend in an opposite direction. The lowering of the general level of the land, while helping, as a rule, to lessen the rainfall, and consequently the rate of

* See Croll, *Phil. Mag.*, May 1868.

subaerial denudation, will at the same time aid the action of the waves by removing under their level the detritus produced by them and heaped up on the beach, and by thus bringing constantly within reach of the sea fresh portions of the land-surface. But even with these advantages in favour of marine denudation, the balance of power will probably, on the whole, remain always on the side of the subaerial agents.

There is probably but little erosion carried on by the sea except where breakers can act, that is along the line where sea and land meet. The ultimate tendency of the erosive action of the waves is to reduce the land to a level under the sea. While this process is in progress many inequalities must necessarily be produced, owing to variations in the power of resistance of the rocks, the set of tides, currents, etc. Hence arise bays and promontories, peninsulas and islands, with all those varieties of contour with which we are so familiar along the seaboard of our country. But these irregularities, if long enough exposed to denudation, are in the end planed down to a tolerably uniform surface under the sea-level. Thus, while subaerial denudation tends to cut down the land into valleys, marine denudation labours to reduce the land to a great submarine plain.

II. The Results of Denudation.

We have now to consider the more important of the general results brought about upon the surface of the land by the action of the various forces of denudation. They may be conveniently treated under three heads :—α. Proofs of the removal of a great thickness of rock from the general surface of a country. β. Subaerial denudation gives rise to valley-systems and hills. γ. Marine denudation tends to form plains. In the next chapter we shall consider the combined influence of subterranean and surface movements in producing the present configuration of the land.

a. Proofs of the Removal of a Great Thickness of Rock from the General Surface of a Country.

There is probably no large region of the globe which does not show evidence of extensive denudation. In most countries it is easy to prove that the present surface has been produced by the removal of a great thickness of solid rock, by which it was originally covered. The proof is furnished by the geological structure of each district, and though of great simplicity, requires an acquaintance with some of the elementary principles of geology for its proper comprehension.

1. When, in a district composed of horizontal or gently inclined strata, we find wide valleys, along the sides of which the edges of the strata are seen rising one over another, and also detached hills formed of the same

strata, but widely separated from the main mass of them, we readily perceive that a great body of rock has been removed. In Fig. 134, for example, the beds which abut against the sky-line along the escarpment A, have evidently at one time been prolonged to the right, so as to join with those of the outlier B, and extend still farther beyond D. This abrupt truncation of strata by the present surface is a proof of denudation. The excavation of the valley C, the isolation of the hill B, and the formation of the low country stretching to the right of D, are the work of denuding agents, acting upon the gently inclined strata 1, 2, 3, 4, etc. Many admirable illustrations of this simplest evidence of denudation are furnished by the escarpments of the secondary and tertiary formations of the centre and south of England.

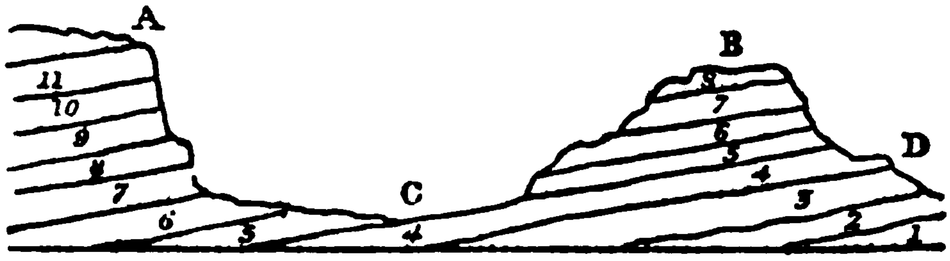

Fig. 134.
Escarpment and Outlier.

2. But even if there are no valleys or outliers, the mere fact of the strata cropping to the surface is evidence of denudation. In Fig. 134, the truncation of beds 5 and 6 by the surface of the valley C, is proof that they have been denuded. If the escarpment and outlier had been worn away, and the surface of the valley C had extended over their site, the appearance of the successive outcrops of the beds would have been, to a geological eye, as satisfactory proof of the reality and amount of denudation as if the escarpment and outlier had remained. Nay, more, these outcrops along a level or rolling surface would have in reality proved a greater amount of denudation than the escarpment and outlier do, for by protracting the angles of inclination of the strata, we learn that the latter must once have risen high above the present surface. This kind of evidence is sometimes singularly striking in a country where the dip of the rocks is more highly inclined. In Fig. 42 (p. 188) the strata which rise to the surface at angles varying from 35° to 50° must have extended much farther upward than they do now, though they furnish us with no means of ascertaining how far they did extend.

3. But in cases where the strata are not only inclined but thrown into folds, we obtain evidence of at least the minimum amount of denudation. This will be understood at a glance if the reader will turn back to Fig. 47 (p. 193). The anticlinal axis A, and the synclinal trough B, have there been both planed down to form the present surface, the dotted lines above that surface representing a portion of the mass which has been removed. Now, if the thickness of strata between beds 7 and 11 be, say 1000 feet, then there must have been at least 1000 feet of rock worn away from the top of the fold A. This would be the minimum amount, but in reality the total quantity of rock

removed would be much greater, for the beds above No. 11, now found on each side of the anticlinal axis, once covered it, and have since been denuded. Again, in Fig. 84 (p. 222), an illustration is given of the way in which an approximate estimate may be formed of the extent to which a country has suffered denudation. If we ascertained by measurement that the slates between the highest and the lowest conglomerate in that diagram were 5000 feet thick, it would be evident that, from the top of the anticlinal fold, a depth of rock of more than that amount must have been removed. Many instructive sections of this kind may be found in the writings of Professor Ramsay.* He shows that in South Wales a thickness of in some places as much as at least 11,000 feet of rock has been removed from what is now the surface of the country.

A remarkable fact has been frequently noticed in districts where the rocks are much folded, namely, that the present surface bears no relation to the folds, but has been worn across them. Hence a level or gently undulating tract of ground often lies upon rocks that have been folded, and even violently contorted. This can only be explained by the working of denudation. Wales, as Professor Ramsay long ago showed, affords many characteristic examples. The great Carboniferous plain of Ireland also illustrates the way in which a level surface may be worn out of tilted and convoluted rocks (Fig. 135).

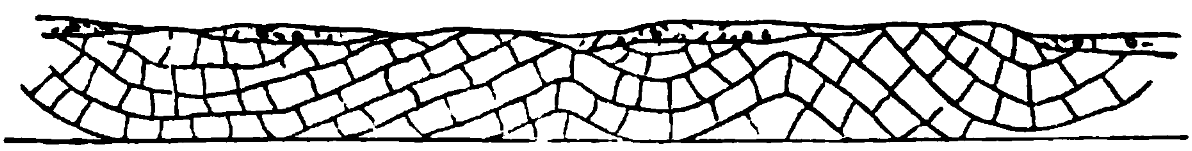

Fig. 135.

Representing general structure of central plains of Ireland, formed of undulating beds of the lower part of the Carboniferous limestone, covered here and there with limestone gravel. (Jukes.)

The rocks on which that plain lies consist chiefly of beds of the lower part of the Carboniferous limestone, from which the Coal-measures and upper parts of the limestone have been removed; a general thickness of 2000 or 3000 feet at least, perhaps even 5000 or 6000 feet of rock, being thus lost. In the south of Ireland the denudation is made

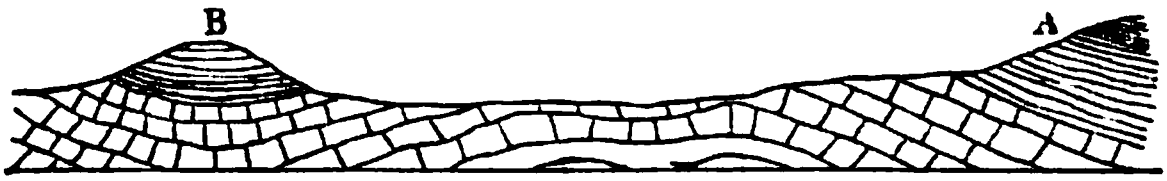

Fig. 136.

Escarpment A and Outlier B of Irish Coal-measures, overlooking plain of Carboniferous limestone. (Jukes.)

more apparent by the occasional preservation of fragments of the sheet of Coal-measures which formerly covered the country (Fig. 136). The

* See his paper "On the Denudation of South Wales," *Mem. Geol. Surv.*, vol. i.; also his "Memoir on the Geology of North Wales," *Op. cit.*, vol. iii.

low lands of Wexford and other parts of the island are underlaid in like manner by highly inclined and often contorted Lower Silurian and Cambrian rocks. In Scotland the broad uplands of the southern counties lie upon similar rocks, while the Highlands afford many striking examples of the denudation of vast anticlinal and synclinal folds.*

What is true of the British Islands is equally so of the rest of the world. Everywhere we find that plicated rocks have been worn down until no trace of the foldings is retained by the present form of the ground. In Scandinavia, the great table-land out of which the western fjords have been cut, consists of crumpled and inclined metamorphic rocks. The greater part of Canada lies upon folded and contorted palæozoic strata. A great proportion of the United States is underlaid by folded rocks, which sometimes, as in the Appalachian chain, have been bent into the most remarkable plications and enormously denuded.†

(4.) Perhaps, to a geological eye, the most striking evidence of all as to the extent to which the general surface of a country has been lowered by denudation, is furnished by the way in which all superficial indication of large dislocations has been effaced. It is not uncommon to meet with a fault where the strata on the one side have been elevated or depressed 500 or 600 feet above or below those on the other; but it is rare to find any effect of such a dislocation on the surface of the ground. In our coal-fields, where, from the much more detailed examination which they receive, faults are observed in greatest abundance, we sometimes find a district which, from the mining-plans, is seen to be a net-work of faults, of all sizes, up to a hundred fathoms or more, yet shows at the surface only a level stretch of corn-fields and meadows. In all these instances there can be no doubt that a great thickness of rock has been removed.

In the south of Ireland a remarkable illustration is afforded by the Slievenamuck fault, near Tipperary.‡ This great dislocation has a throw of not less than

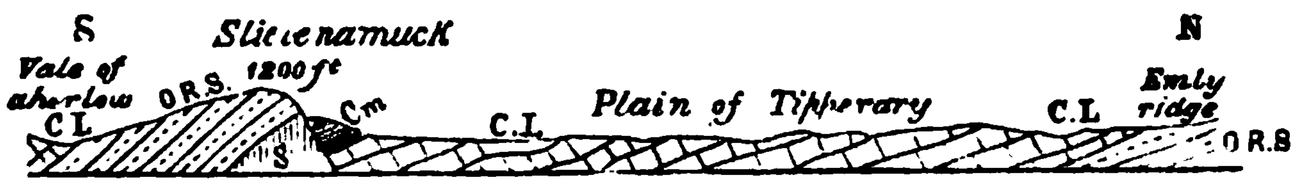

Fig. 137.

Section showing the Slievenamuck fault, near Tipperary.

Cm. Coal-measures. O. R. S. Old Red Sandstone.
C. L. Carboniferous Limestone. S. Silurian Rocks.

4000 feet, seeing that it brings down the Coal-measures against the Silurian rocks (Fig. 137).

* See Murchison and Geikie, *Quart. Journ. Geol. Soc.*, vol. xvii. p. 171; and *Scenery of Scotland*, chap. v.

† See the sections in Roger's *Pennsylvanian Survey*, also in his Map of America, in Keith Johnston's *Physical Atlas*.

‡ This description was given by Mr. Jukes in last edition of this Work, from which also Figs. 135 and 136 are taken. The geological features he describes may be found traced by him on his *Geological Map of Ireland*, published by Stanford.

The Coal-measures here are about 800 feet thick, and rest on Carboniferous limestone, of which numerous beds crop out towards the north, making a total thickness apparently of not much less than 3000 feet. From underneath this limestone certain beds of sandstone, called Old Red Sandstone, crop to the north, forming a low hill, which may be called the Emly Ridge. The thickness of this Old Red Sandstone is not there determinable. In the country to the south, however, we get the same Carboniferous limestone in the vale of Aherlow, with the same Old Red Sandstone rising from underneath it, and forming a hill called Slievenamuck, 1200 feet high. In this hill its beds are well seen, nearly from top to bottom, and their total thickness cannot be less than 1000 feet. Moreover, on the northern slope of this hill, the bottom beds of the Old Red Sandstone are exposed, and may be observed to rest on the uptilted and previously denuded edges of certain slates and grits which are of much greater geological age, and probably belong to the formation known as Lower Silurian, and some thickness of these is shown on the face of the hill. But on descending the hill, a little lower, we come suddenly on to the Coal-measures dipping at a gentle angle to the south, and abutting directly against the Lower Silurian rocks. This proves that there is a fault there, with a down-throw to the N., equal to the whole amount of the thickness of the rocks above mentioned, namely, 1000 feet of Old Red Sandstone, 3000 feet of Carboniferous Limestone, and 800 feet of Coal-measures, or, taking a minimum, 4000 feet.* This section, when examined in connection with the surrounding district, is a very instructive one. We may learn from it—

1*st*. That the rocks called Lower Silurian were greatly disturbed and denuded, so as to have a surface formed across the edges of their beds before any other rock was deposited upon them.

2*dly*. That upon the surface so formed the series of sandstones called the Old Red Sandstone were deposited horizontally, and without any disturbance, and that the whole of the Carboniferous limestone and the Coal-measures were similarly accumulated over the Old Red Sandstone, in regular unbroken order, by parallel or "conformable" deposition, so as to make a thickness of horizontal beds at least equal to 4000 feet.

3*dly*. That subsequently to the deposition of the last of these beds disturbance took place, the rocks were lifted up, tilted and broken through, and that dislocation took place to the amount just stated.

4*thly*. At the time that this dislocation took place the Coal-measures must certainly have existed generally over the surface, or the dislocation would not have brought down beds belonging to them—a conclusion confirmed by the occurrence of other isolated patches of Coal-measures still existing all round the district at the distance of a few miles from this spot.

5*thly*. Since the disturbance of the country denudation has removed all the Coal-measures from off the district except the patches mentioned above, and, moreover, has removed large portions of the upper part of the Carboniferous limestone, since the lower beds of that formation now appear at the surface in the greater part of the neighbourhood. But it has done more than that, for in those spots where the Old Red Sandstone now forms the surface rock, not only the whole of the Coal-measures but the whole of the limestone must have been removed, and, moreover, it has cut deeply into the Old Red Sandstone, and in some places right through even that, and swept it clear away, so as to re-expose the old denuded surface of the Lower Silurian rocks, on which the Old Red Sandstone was deposited, and has even gone yet further still, for this more recent denudation has in some adjacent localities, especially along the northern slope of the Galty mountains, which lie south of the vale of Aherlow, eaten down so as to

* See Sheet 6 of the Horizontal Sections, and Explanation of Sheet 154 of the Maps of the Geol. Survey of Ireland by Mr. J. O'Kelly.

wear deep hollows and valleys into the Lower Silurian rocks themselves, several hundred feet below that surface on which the Old Red Sandstone was deposited.

But the conclusions deduced from the examination of the structure of this part of Tipperary may be extended to the whole of Ireland, over the greater part of which the above-named formations are to be found undulating above and below the present surface of the ground, the Coal-measures coming in generally as high land, resting in a basin of the Carboniferous limestone, as at B, Fig. 136, and the Old Red Sandstone and Silurian rocks rising out from underneath the limestone often into hills still loftier than the highest parts of the Coal-measures, and commonly causing great anticlinal curves in the Old Red Sandstone. The Commeraghs, the Knockmealdowns, the Galtees, the Slievebloom, the Keeper group, and the higher mountains of Kerry and Cork generally, all come within the latter class. Fig. 138 is a diagrammatic section running from W. to E. across the

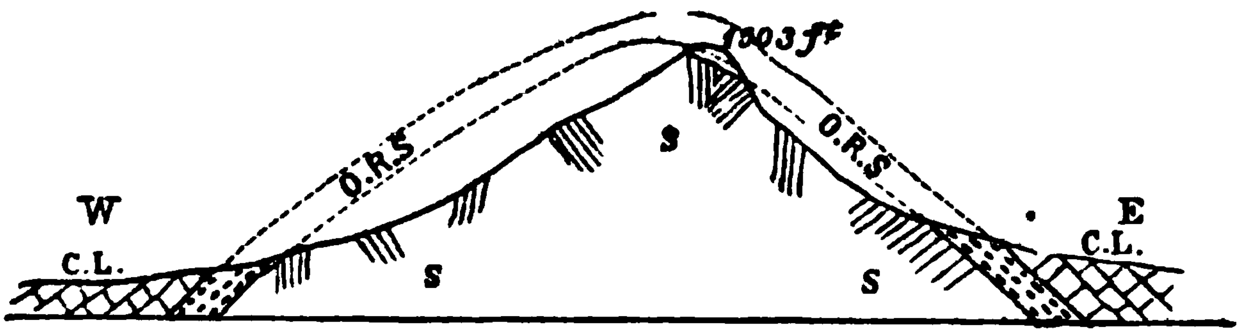

Fig. 138.

Diagrammatic section across the Devil's Bit Mountain.

C. L. Carboniferous Limestone.

O. R. S. Old Red Sandstone, its denuded part being shown by the dotted lines.

S. Lower Silurian rocks.

"Devil's Bit range," a part of the Keeper group where the original anticlinal form of the Old Red Sandstone is proved by a small capping of it left on the summit of the hill.* Farther south and south-west of this point the Old Red Sandstone is much thicker, and has not therefore been so often worn through by the denudation as in the Keeper and Galty groups.

β. Subaerial Denudation gives rise to Valleys and Hills.

If the present action of air, rain, springs, rivers, and ice, is their normal one, and we have no evidence that it is not, then, since that action is greatest along the lines whereby the drainage is returned to the sea, its general effect upon the land must necessarily be to carve out systems of valleys. If we reflect adequately upon the mass of debris which every river annually removes from its basin and carries out to sea, we are led to realise the truth of Hutton's doctrine, that "the great system upon the surface of this earth is that of valleys and rivers; and that, however this system shall be interrupted and occasionally destroyed, it would necessarily be again formed in time while the earth continued above the level of the sea."† Subterranean movements may, in any particular instance, have aided the operation of the meteoric forces. But this co-operation is not absolutely necessary. Were

* See Mr. A. B. Wynnes' description of this district in the Explanations of Sheets 135 and 145 of the Geol. Survey of Ireland.

† *Theory of the Earth*, vol. ii. p. 538.

a mass of land, without a single valley, but with a smooth surface sloping gently seaward from its central portion, to be elevated above the ocean, and exposed to the atmospheric agents of denudation, a system of watercourses and valleys would certainly be excavated.* Nor, as we have already seen, would a long series of geological periods be necessary for such a result. At the present rate of erosion, valleys 800 feet deep might be carved out in a million years.

If, on the other hand, a portion of the earth's crust, crumpled and fractured in the extremest degree, were raised above the sea, it would at once begin to yield to denudation. Unless its upheaval were too rapid, it would, as it rose, be battered and worn down by the sea. Its surface would crumble away, and the original features, due to subterranean movements, would gradually disappear. These features would doubtless, at first, greatly affect the lines of drainage, and their influence would continue to be traceable until it waned and disappeared along with the features themselves; and, as Hutton showed, the normal system of valleys of erosion would necessarily be restored.

While the obvious and direct effect of subaerial denudation is to give rise to valleys, it is evident that, as the valleys become widened and deepened, the ground between them will be left standing out as ridges and hills. The form of these less denuded portions of the land-surface must be subject to infinite variety, according to the position of the valleys, the hardness or softness, and the varying geological structure and grouping of the rocks. But these varieties ought not to conceal from us the fundamental fact that the hills exist, because the valleys have been carved out of them. The very varieties of form, as we shall see in the next chapter, are themselves in great measure brought out only in the course of denudation.

γ. Marine Denudation produces Plains and Table-lands.

If the various destructive elements have acted upon the surface of the land in past time with any approach to the proportions in which they are acting now, it seems to be clear, from the various considerations which have now been adduced, that the sea can have played but a secondary part in modelling the outlines of a continent. It may, perhaps, be objected to this conclusion, that the traces of wide level tracts, known as plains of marine denudation, so commonly to be met with over the earth's surface, can only be attributed to sea-action, and must prove the sea to have had no small share in the general task of planing down the land. These plains are, indeed, in all probability, referable to the action of the sea; but if we reflect upon the tendency of atmospheric waste, we must perceive that such plains are the natural and

* See the passage in Playfair's *Illustrations*, sec. 99.

necessary result of that waste. In short, "a plain of marine denudation" is that sea-level to which a mass of land has been reduced mainly by the subaerial forces; the line below which further degradation became impossible, because the land was thereafter protected by being covered by the sea. Undoubtedly the last touches in the long process of sculpturing were given by the waves and currents, and the surface of the plain corresponds with the lower limit of the action of these forces. Yet I cannot but believe that in the past history of our planet the influence of the ocean has been far more conservative than destructive. Beneath the reach of the waves, the surface of the abraded land has escaped the demolition which sooner or later overtakes all that rises above them; and there, too, in those submarine depths, the sedimentary materials have accumulated, out of which the existing continents have been framed.

δ. Denudation as a Measure of Time.

In the foregoing pages denudation has been treated as a process now advancing before us, and producing certain measurable results. What is happening now has happened also in the past. We cannot pursue geological history for even a short way backward, without encountering on every side proofs of continued and enormous denudation. We see that in the past results have been effected exactly similar to those which are accomplished at the present time, and we infer, with confidence, that the similarity of result indicates an identity of cause—that the agents which are denuding the surface of the earth to-day are the same as those which have denuded it in former ages. It is not necessary, however, to assume, as is too often done by modern geologists, that the present rate of change has always been uniform, and must be taken as the measure for all past and all future time. Though we have good reason to believe that denudation in the past has been the result of the same agencies by which it is still produced, we are not warranted to conclude that these agencies have always acted in precisely the same proportion and at exactly the same rate. The present system may, indeed, represent a fair average, as it is certainly the only one on which we can safely base any speculations regarding the past changes of the earth's surface. But we must not dogmatically assume that no other rate of change could have been possible, or that uniformity of causation, as measured by human experience, is an established truth. The circle of that experience is still too narrow to justify such assumptions. Only within the last few years Mr. Croll has taught us how materially the changes in progress upon the surface of the earth may be modified by cosmical causes, which recur at certain definite intervals.* And there

* See *Phil. Mag.* for August 1864:—the first of a remarkable series of papers, in which astronomical data are brought into the service of geology.

may remain other influences to be discovered which have told upon the mutations of our planet's surface, and which, therefore, will need to be taken into account by the philosophical geologist.

But though we are not at liberty to assert that the present rate of change upon the earth's surface has been on the whole uniform from the earliest geological times, nevertheless, as it is the only rate of which we have any actual experience, and as it accords with all evidence of changes in the geological past, we seem to be warranted in the meantime in assuming it as an average. If the rate has varied, and most probably it has done so, there is some reason to suppose that the variations have, on the whole, tended rather to the increase of denudation; or, in other words, that the present rate, if not an average, is rather below the mean than above it. In taking the existing rate, therefore, as an average from which to speculate upon past changes, we shall not be likely to exaggerate the results.

When we calmly look at what the various denuding forces are now doing, and when we try to gain a vivid idea of the loss of land by measuring the amount of material which is annually removed from land-surfaces, we cannot but be struck by the unexpected rapidity of the process. Denudation is commonly appealed to as one of the geological phenomena, which, as measured by results, best attest the enormous duration of geological periods. And this conclusion is based upon the idea that the present rate of denudation is inconceivably slow. Yet, as we have seen in the previous pages, the rate of waste actually in progress would, in a few millions of years, suffice for the washing away of all the solid land on the face of the globe. The proportions already given for the rate of waste among the different agents of denudation, and in different areas of the globe, may be modified, but the general result will doubtless remain, that modern denudation is in reality a far more gigantic and rapid process than we have been apt to believe, and that our demands for enormous periods, in so far as based upon the evidence of past denudation, are unnecessary.

Denudation and deposition are phenomena inseparably connected; the one is the counterpart of the other. If, therefore, all evidence from living nature goes to show that geologists have been in error in requiring too vast a time for the removal of large masses of solid rock, the same evidence suffices to indicate that they must be equally wrong in demanding enormous periods for the accumulation into stratified rocks of the material so removed. The whole of that chain of reasoning which, assuming the extremely slow rate of waste of a land-surface, and the inconceivable tardiness of the growth of a thick mass of stratified deposits, deduces therefrom the incalculable duration of even a single geological period, seems to break down when tested by the facts of modern denudation.

Recent researches in physics, as we have already seen, go to show that the unlimited ages so often demanded by geologists cannot be granted.* It is well, therefore, to find that these demands, in so far as questions of denudation are concerned, are really unnecessary, that even the facts of the science itself do not require such exorbitant drafts upon the past.

* See *ante*, p. 325, and *note*. Thomson, *Trans. Geol. Soc. Glasgow*, iii. parts i. and ii. also Phillips, *Life on the Earth*, p. 119; Haughton's *Manual of Geology*, pp. 82-99.

CHAPTER XXVI.

PHYSIOGRAPHY—ORIGIN OF THE EARTH'S SURFACE OUTLINES.

THE present external configuration of land-surfaces and the form of the ocean-bed are the result of the working together of those underground and surface agents which we have now passed in review. It remains in this chapter to inquire briefly what, in that prolonged operation, has been the relative share performed by each of the two great classes of agents.

When the surface of the planet had sufficiently cooled to permit of the condensation of an ocean, we may believe that it was already marked with irregularities, and that, while the sea filled up the depressions, the more important ridges rose up as land. It has been argued that the primeval contour thus produced has been ever since retained, though modified by subsequent changes—that the present trend of our continents is that of the first land that emerged from the earliest ocean. It is possible that the lines of elevation consequent on the early contractions of the earth's mass, may have continued to be lines along which elevatory movements took place in after ages. But that any trace of the actual primitive mountain-chains is now visible, may be confidently denied. From what we know of denudation in progress, it is evident that no land-surface could remain above water more than a few millions of years, unless the wasting powers of the denuding agents were compensated by elevation from below, and consequently that no original excrescence on the earth's surface could survive. Moreover, an examination of the structure of mountain-chains shows that, even in the oldest of them, the rocks of which they chiefly consist were deposited as sediment on the floor of the sea, and that their elevation into high land belongs to far later geological periods. What is thus true of mountain-chains is true also of all land-surfaces. The vast majority of the rocks of which the dry land is formed was originally deposited under the sea. Consequently, the dry land is due to subsequent elevation, and as the sea-formed rocks are of many different ages, the land has not been produced by one elevation, but is the result of a long series of upward and downward movements.

Our knowledge of the geological structure of the globe is, perhaps, still too imperfect to warrant any detailed speculations regarding the

history of the movements by which the present distribution of land and sea has been brought about. Until that knowledge is more complete, it seems premature to generalise regarding the progress of the upheaval of the continents and the depression of the oceans. Starting from the broad fact that our continents are the result of upheaval, and our ocean-beds of depression, we may more profitably at present proceed to inquire what is the nature of the processes which have resulted in the formation of the heights and hollows of the land—our hills and mountains, valleys and ravines, lakes and plains.

Many geologists, whose names have attained the greatest eminence, have yet not sufficiently distinguished the forces which have produced the external forms of the land, from those which have adjusted its internal materials. The rocks of which most of our mountains are formed have been so obviously bent and broken, uptilted and uplifted into their present positions, by internal forces of disturbance, that it has been hastily concluded that the fractures and contortions of the rocks, the direction of the slopes of the surface over them, and the forms of the hills made of them, have all had one common origin. It is often forgotten that if the present surface slopes had been adjusted at the same time as the internal structure, they must both have been in existence before that time. The present surface of the hills, then, must have existed as a surface before the hills were elevated; but, as the summits of the hills often expose the most deeply-seated rocks, it would follow that the surface which exposed those rocks before they were raised into hills must have been that of deep excavations or hollows. It would also follow that the movements of elevation which lifted the rocks so as to form hills acted chiefly on the areas which had been thus excavated, so as to invert them, like so many glove-fingers, and push up the rock exposed in the deepest hollow till it formed the loftiest eminence. In short, the hypothesis necessarily lands us in absurdity, and shows the necessity of distinguishing between the forces which gave a position to certain masses of rock on the one hand, and those which have imparted external form to it on the other.

Most of the misconception on this subject has arisen from the use of exaggerated diagrams, and from neglecting to begin by deciphering the true geological structure of the ground before proceeding to reason upon the history of its external features. It cannot be too early or too strongly pressed upon the student to accustom himself from the beginning to draw his sections on a true scale, vertical and horizontal, and to insert upon them at first only the evidence which he has been able to procure regarding the dip and curving of the rocks. By this means he will learn more vividly and instructively than in any other way how completely the present surface of the ground is a sculptured surface, carved out by denudation, and how little, as a rule, it is affected by the dislocations,

upheavals, and convolutions of the rocks underneath it.* He will find that whatever may have been the original effect of these subterranean movements upon the surface, they have not formed the existing surface, which has been worn down during the removal of hundreds or thousands of feet of the fractured and crumpled rocks. Recognising that subterranean agencies have raised the sea-bed into dry land, and that mountain-chains are portions of the land which have been upheaved farther than the lower grounds, he will yet come to perceive that the wearing down of the mountains to their present form, the carving out of glen, and valley, and ravine, the isolation of huge hills, the excavation of deep lake-basins, the levelling of wide table-lands and plains, have all been the work of the surface agencies of denudation.

It was the profound and far-seeing remark of Hutton, that the great central feature and key to the history of a land-surface is its system of valleys. In the following pages, therefore, we shall examine the structure and origin of—1. Valleys, with their subordinate features, as ravines, passes, and lakes; 2. Plains and table-lands; 3. Mountains and hills.

1. Valleys.

Valleys of all kinds, from the most open to the most narrow and profound, are hollows worn by erosion. They have frequently been eroded along the crest of an anticlinal curve, which gave rise to the mistaken notion of the so-called "valley of elevation,"—a notion of which the ghost still haunts some parts of the geological world. The only other possible mode of forming a valley than that of erosion is by the growth of hills in such close proximity as to give to the unfilled spaces between them the appearance of valleys. Such features may occur between closely adjoining volcanic cones. They may also be formed on a minor scale between rows of sand-dunes. Earthquakes sometimes form fissures at the surface, and torrents may take advantage of these to commence the formation of ravines. But without a torrent no earthquake fissure ever becomes a glen or ravine, still less a valley.

The direction along which the external forces shall produce most effect, or along which they shall be set to act, may often depend on something which is the work of internal force, such as lines of anticlinal or synclinal fold, lines of fault, or boundary lines of formations; but it is the direction only which is so governed. The external features produced in that direction are produced by external action.

An illustration of the way in which erosion carves out a system of valleys on a land-surface is furnished to us by what takes place daily

* The writer may perhaps be pardoned if he refers the student to the published sections of the Geological Survey, as a pattern for his guidance. These sections are still unique, though they have served as models in other countries as well as in our colonies.

along the coast. If we watch the tide receding from a flat muddy coast, we see that the mud-flat, even where no fresh water drains over it from the land, is frequently traversed by a number of little branching systems of channels, opening one into the other, and tending to one general embouchure on the margin of the mud-flat, at low-water mark. The surface of the mud is not a geometrical plane, but slightly undulating; and the sea, as it recedes, carries off some of the lighter and looser surface-matter from some parts, thus making additional hollows, and forming and giving direction to currents, which acquire more and more force, and are drawn into narrower limits, as the water falls. Deeper channels are thus eroded, and canals supplied for the drainage of the whole surface. First two, and then more, of these little systems of drainage unite, until at dead low-water we often have the miniature representation of the river system of a great continent (wanting of course the mountain-chains), produced by the very agent—namely, running water—by which all river systems, on all islands and continents, have been produced. But although running water was the agent in both cases, the water in the one case was that of the sea, in the other that of the atmosphere. The daily rise and fall of the tide over the mud-flat, and the repeated drainage action thus kept up on it, would be but feebly imitated by the rarely occurring rise and fall of the land through the upper surface of the sea.*

The repeated drainage action of the falling tide finds its analogue on the land in the drainage action of the falling rain. This water, diffused at first over a large surface, partly sinks into the ground, but the remainder flows or soaks down the nearest slope, till it meets a rise of ground that turns it aside. The united waters of the two slopes then run down the line between the two, and begin to cut a channel along that line. What happens in one part of the area happens in others, and the various channels unite and form streams, ever increasing in volume and power on their course towards the sea. If these streams at first unite in a basin and form a lake, they must ultimately fill that basin till it overflows at its lowest point, and the escaping stream commences to cut a gorge there which will in the end drain the lake.

The direction in which these rivulets and their resulting rivers may flow, the number of them that may unite to form one main stream, and the place where that stream may finally enter the sea, depend on the original form of the surface of the ground and the quantity of rain that falls upon it, as well as on the nature and position of the rocks that lay below that original surface. When the land was first upraised above the sea it would have some central line or point where the elevation was greatest, and which would consequently form the line or point of

* This illustration is from last edition of this work.

watershed. The surface of the new land, even if it were a plain of marine denudation, must have had many inequalities. Of these, the rain, descending in rivulets and large streams, would avail itself, choosing ever the lowest levels and the nearest paths by which the water could find its way to the sea. The paths, when once taken, would be retained, deepened, and widened, while the general surface of the whole country was at the same time being lowered by the various agents of subaerial denudation. The retention of the draining water in old channels would be more certain in proportion to the steepness of the ground and consequent rapidity of the flow of water; and channels would there be most rapidly deepened. Such deep valleys or ravines are scarcely to be obliterated, or otherwise altered than from deepening and enlargement, by any number or amount of changes, short of the removal of the mass of high ground which they traverse. As long as the mountains remain undestroyed, the valleys and ravines must obviously be continually enlarged, both vertically and laterally, by the action of the waters which traverse them.

In this system of valley-carving the form of the ground on either side of a river-course would mainly depend on the nature of the underlying rocks, and the relative potency of the river and of the other agents of subaerial denudation. When the rocks traversed by the river were but feebly disintegrated by the atmospheric influences, in comparison to the erosion carried on by the river, the ground would remain high, and the river-valleys narrow, deep, and precipitous. Where, on the other hand, the rocks offered less resistance, the valleys would become more open, and their sides more gently sloping; and where the rock masses were easily affected, the valleys would expand into plains, often of such a width and extent that their dependence on the original river-valley might cease to be apparent. Still that dependence would be proved by the fact of the tributary streams flowing, however sluggishly, into the main original river, and the whole surface of the dry land, being divisible into river-basins, separated by narrow lines of watershed (*divortia aquarum*), or lines which shed or separate one system of running waters from another.

The author of this Manual was, in the last years of his life, one of the foremost advocates of the erosive origin of valleys, and to his elucidation of the history of the river-valleys in the south of Ireland much of the recent progress made by geologists in this branch of their science is to be ascribed. He has left the following resumé of his researches for insertion in the present edition of this work:—

River-Valleys of the South of Ireland.—Although I had for many years seen clearly that the external features of the earth's surface were due to direct external action, and not to that of any internal force, yet such is the influence of early training, that when I was preparing the second edition of this work I was

only groping my way to a proper appreciation of the difference between marine and atmospheric denudation. I was suddenly enlightened about the time of its publication, in the year 1862, by arriving at the solution of a problem that had puzzled me for many years. Many of the principal rivers of the south of Ireland, after running for miles over low plains which have broad sea-margins, in several directions, instead of issuing over those open spaces to the sea, go out of their way to cut through hills, sometimes even through isolated groups of hills, that are surrounded by the low lands. Other rivers, after running for many miles along well-marked valleys, which continue with straight courses right out to the sea, instead of following down those valleys suddenly turn at right angles, and cut, by comparatively deep and narrow ravines, through the hills that bound the valleys, and escape to the sea in that direction.

The old explanation of these facts was, that these ravines through the hills were cracks opened by internal force, but this was in reality a mere hasty guess, and no real explanation. The ravines cut through the hills are narrower and have steeper sides than the valleys, but they are evidently not the mouths of gaping fissures. Their depth is, after all, insignificant as compared with their width. A transverse section across them, drawn on the true scale, shows them to be squarish gaps of erosion, ending suddenly and completely downwards. In some cases the beds can be traced unbroken across the floors of these ravines. They are obviously channels that have been cut out of the rocks, by the removal of the parts that once intervened between their sides. Even in mountain glens an error is often made by hasty observers, who adduce the apparent correspondence in the curves of the opposite sides of the glen as proof that they once fitted into each other, and that the rock surfaces now exposed actually touched each other, and have gaped asunder; while, if they took the trouble to explore the floor of the glen, they would find that, wherever the rocks can be seen, unbroken beds stretch across it, coming out from beneath the base of one cliff and passing under the base of the other. The surfaces of those unbroken rocks on the floors of the glens have obviously been bared by denudation, and the student may rely that this is true for all cases, and that, except perhaps in districts recently convulsed by very bad earthquakes, there is no such thing in the world, certainly not in the British Islands or Western Europe, as a glen, ravine, or valley, that is the mouth of a fissure which has gaped open. The whole space between the sides of the glens was once occupied by rock that has been carried away.

What then is the origin of these gaps or ravines through the hills, which are now selected as channels by the rivers, instead of the seemingly much more easy and natural courses offered by the valleys or the plains?

The solution of the problem which I arrived at was this, that the rivers formerly ran upon a gently undulating surface, which was considerably above that of the present valleys and low lands; a surface, of which the summits of the existing hills perhaps formed a part, or closely approximated to it; and that the rivers which first began to run over this old surface have continued to run on it during the whole of that wasting action of erosion which has worn down the old surface into the present one. The rivers taking directions according to the slopes of the old surface-cut channels, which in many cases happened to run across the spaces where hills were subsequently disclosed by the removal of the envelope around them. But as the waste of that envelope could only be removed by the rivers themselves, those channels must always have been deeper, even though but a little deeper, than the level of the surface of the interior plains and valleys.

This, then, shows the subaerial character of the whole action. Had the country ever been depressed below the sea during the time, and any erosion of the surface of the plains and valleys been caused by the sea, the rivers would hardly have regained their old channels through the hills, on the re-elevation of the country into dry land. It can be shown in many cases that if a dam of slight

elevation were now constructed across some of the ravines, and the rivers ponded back, the waters would escape down the valleys or over the plains, entering the sea by altogether different mouths from their present ones.*

Valley of the Blackwater.—A clearer illustration of the views now enunciated could not be selected than that afforded by the river Blackwater, which runs by Mallow, Fermoy, and Lismore. The parts of the counties of Cork and Waterford which are here adjacent to each other, consist of a number of alternate ridges and valleys, which run with great regularity, almost exactly east and west, for fifty or sixty miles. The hills are formed of anticlinal folds of red sandstones and slates (belonging to the Old Red Sandstone formation), while the valleys have synclinal curves of thick grey limestone (Carboniferous limestone) for their subjacent rock.

The loftiest hills of the district are those called the Knockmealdown mountains, which rise to 2600 feet above the sea. These, however, decline towards the west, and finally sink in that direction beneath a limestone plain. The sandstone ridge which runs parallel to them on the south, and is thereabouts called Drum, is much lower but broader and more persistent, and is continued in fact from the southern side of Dungarvan Bay, right across Ireland, to the coast of Kerry. The highest points of the Drum ridges are from 600 to 900 feet above the sea, but as they run towards the west they increase in height (as the Knockmealdowns decline), and form the Ragle mountains, and other still loftier hills farther west.

The limestone valley of Lismore, between the Drum ridge and the Knockmealdown hills, is a narrow, well-marked trough, both externally and internally. It runs in from Dungarvan Bay to Fermoy, a distance of forty miles, and a road might be taken the whole of that distance without ever passing over ground much more than about 100 feet above the sea. It is just north of Fermoy that the Knockmealdown ranges finally die away, while to the west of that the southern ridge gets loftier, and forms an unbroken watershed the whole way to Mangerton and Bolus Head. The Blackwater river, rising in Kerry, runs at the foot of this ridge for fifty miles down to Fermoy, and continues in the same

* The application of these views to the explanation of the peculiarities in the lower parts of the courses of some of the rivers of the south of Ireland, is given in a paper published in 1862, in the 18th volume of the *Quarterly Journal of the Geological Society of London*. After reading it, I learnt from my colleague, Professor Ramsay, that the idea of the old plain of denudation, coinciding with the tops of our present hills, had struck him long before, on seeing how nearly a straight line would touch the summits of the hills, in the sections across South Wales, drawn and published by the Geological Survey. He pointed this out to the British Association in 1847, in a paper, of which an abstract is given in the volume for that year. He, however, then, in common with most geologists, looked to the sea as the main agent of denudation, which had produced the form of the surface of our present lands. I believe that my paper, above alluded to, first showed that that plain, the existence of which I had also arrived at independently from the study of our Survey Sections, not only became dry land, but was worn by rain and rivers into its present form. The ideas, however, were but a re-awakening of the dormant principles of Hutton and Playfair, and were evidently floating in the heads of many of my colleagues and other observers, as is shown by the numerous papers that have since appeared, in which they are applied. See, for example, Professor Ramsay's *Physical Geography and Geology of Britain*, and his papers in the *Phil. Mag.* for 1864-5; Mr. Geikie's *Scenery of Scotland, viewed in connection with its Physical Geology*; and papers by Dr. Foster, Mr. Topley, and Mr. Whitaker, in the *Quart. Journ. Geol. Soc.*, vol. xxi., and *Geol. Mag.*, vols. iii. and iv. Colonel George Greenwood had previously published a little work called "Rain and Rivers," in which the doctrine of atmospheric erosion is clearly expounded. Dr. Dana had explained the aqueous erosion of the valleys in New South Wales, and in the volcanic islands of the Pacific. Dr. Newberry had called attention to the marvellous system of erosion in the great basin traversed by the Rio Colorado.

straight line down the Lismore valley for about twenty miles farther, to the little town of Cappoquin. There, however, the river suddenly turns at right angles to its former course, and instead of following the regular east and west valley, which continues straight out to the sea at Dungarvan Bay, it cuts through the high land of the Drum ridges due south to Youghal Bay, which is, moreover, five miles farther from Cappoquin than Dungarvan Bay. Why does it take this extraordinary course? Because just to the northward of the bend are the Knockmealdown mountains, and the original river ran due south from near their summits, down the slopes of the original surface, towards the sea.

Suppose we restore in imagination that old original surface, and look at it as it was before any of the valleys were excavated. It would then be an undulating plain, rising into gently sloping hills in different places, the loftiest point being doubtless over the spot where the summits of the Knockmealdown mountains now are. This plain was one perhaps caused by marine denudation. Its slope would probably be such as that indicated by the line A B in Fig. 139. Streams running down this slope from B, and uniting about the part under C, cut a channel below that towards the sea, and that channel has ever since been the outlet for the drainage of a large part of the country to the west of it. The old marine denudation had cut away limestone and sandstone pretty equally to form this plain, represented by the line A B, but as soon as the atmospheric waters began to act on it, after its elevation into dry land, a sensible difference was established between them. The mechanical action of the running water of the rivers would be pretty equal on both kinds of rock, but the limestone would suffer from the chemical solution of the rain water to a far greater extent than would the arenaceous rocks. The surface of the limestone districts, then, would be wasted more rapidly and more generally than those of the sandstones. Moreover, the detritus of the sandstones could only be carried off down continuous slopes, where the water could transport it mechanically, as sand or mud. The dissolved limestone would be diffused through the whole water, would rise with it in

In this figure the darkly-shaded part represents a section across the country, with its present outline. S S, the level of the sea; A B, the supposed ancient surface of the country; K, Knockmealdown mountain (2600 feet); C, the situation of Cappoquin; D, the hill opposite Dromana; G, the hill of Carriglass; and Y, the situation of Youghal. The dotted bands represent the Old Red Sandstone, those crossed by strokes the Carboniferous Limestone.

clear springs, the chemical solution and the removal of dissolved materials being ceaseless and universal. The surface over the limestone districts would therefore sink into valleys and plains, while that over the hard sandstone areas, being only wasted mechanically, would resist the erosion longer, and stand up as hills and ridges. Any bands of soft shales and clays would of course yield more rapidly than the sandstones, or perhaps even than the limestones, and form corresponding low lands and valleys. Still, no part of the surface, even of the most easily erodible rock, would sink lower than the bed of the channel by which alone all the detritus could be carried off to the sea. The little river that originally ran down the steepest slope, from the highest summit, would be the one most likely to receive the greatest rainfall, and would certainly have the most rapid course. It would therefore cut the deepest channel through the rocks. Running across the strike of the rocks, it must run across the hardest as well as the softest, and the depth to which it could cut into the hardest would be the limit of depth to which it could cut even the most erodible bands higher up the stream. Those erodible bands, however, would be worn down laterally on each side of the river, as it cut across them, and tributary streams would thus be formed, which would in time wear those softer bands into broad and open valleys, while many parts of the original river, where it traversed hard rocks, would be bordered by cliffs more or less steep. Glens and ravines, often encumbered with waterfalls, therefore frequently characterise the upper part of the original river among the siliceous hills, as they do occasionally all streams that cut across the strike of the rocks, while the longitudinal valleys formed along the strike of the softer or more easily wasted bands of rock are open, regular, and long, according to the extent of the band along which they are formed. No part of their bottom, however, can be worn lower than the bottom of the channel of the original river into which they fall, since that is in fact the channel by which alone their water and its freight of detritus can be carried off. The longitudinal valley may even be worn back across the courses of many minor transverse streams, and deflect their waters down its course; still, whatever water it brings to the original main channel can only add to its power below, but cannot divert its course. This little original transverse stream is the origin of the whole operation, and the motive power which sets it in action.

When the stream flowing from B to A in Fig. 139 had begun to cut deeply into the rocks below that line, the land on each side of its channel was always being worn down by the rain and the resulting rills. The limestone surface sank into valleys, the surface of the sandstones stood up as hills. A tributary stream cut back along the trough of limestone, under C, for many miles, and eventually formed the river Blackwater, as it is above Cappoquin.

To whatever extent these longitudinal valleys might proceed, none of the waters coming down them could ever cross the original transverse valley that was formed by the little primary river. The Blackwater, that comes into this primary river at Cappoquin, has never crossed it to continue down the remainder of the longitudinal valley to Dungarvan Bay, and could never do so unless something happened to cut a channel lower down that remaining part of the valley, deeper than the channel already cut down to Youghal Bay.

Wealden Area.—The wide district, in the south-east of England, known as the Weald, offers another remarkable illustration of the power of subaerial denudation to carve out a system of valleys. The whole of the chalk which once covered that area has been removed, and its escarpments range along either side of the broad Weald, somewhat like old sea-cliffs—a resemblance which, until recently, misled geologists into the belief that the denudation of the Wealden area had been the work of the sea.*

* See the admirable memoir on this subject by Messrs. Foster and Topley, *Quart. Journ. Geol. Soc.* vol. xxi.; and Professor Ramsay's *Physical Geol. and Geog. of Brit. Isles.*

Rhine and Moselle.—These two streams furnish remarkable illustrations of the power of rivers to carve out winding channels in solid rock. For many miles above their junction at Coblentz, they traverse a table-land of highly-inclined Devonian strata, 1000 or 1200 feet above the sea. Originally, when they began to flow, they wound from side to side over this platform of rock, very much as a river winds to and fro in its alluvial plain. That early curving course they have retained, and have gradually cut it down through the rock, so as to form the well-known scenery of these streams.

The erosion of the Moselle valley is particularly striking.* The table-land on either side of the river is furrowed with numerous narrow ravines, with steep sides, which cut down, as they near the Moselle, to depths of 600 or 800 feet below the general surface of the country, and wind through it with the most sinuous curves imaginable. The Moselle itself works its way through the district by an equally tortuous course, forming loops which, after a bend of some miles, often cut back so as to leave but a narrow ridge between two adjacent reaches of the river. This singularly winding valley is both narrow and deep, being closely environed on all sides by steep precipitous banks, 800 or 1000 feet in height, with frequently hardly more room between their opposing bases than just sufficient for the river itself. It is clear that such deep winding channels in hard rock could not have been excavated by the waters of the sea, or by any other conceivable action than that of water running over dry land, and deflected hither and thither according as it was turned aside by meeting with obstacles or induced by facilities to its passage —in other words, by rivers.

Fig. 140 will serve to explain the difference between the wide-spread early and possibly marine denudation by which the general surface of the country, A, B,

Fig. 140.

C, D, has been produced, in consequence of the removal of the rock marked by the dotted lines, and the local river action which has cut down below that surface so as to form the ravines *x*, *y*, *z*. The letters *v*, *c*, refer to volcanic rocks of comparatively recent date.† It is obvious, from the patches of lava now found in the bottom of the valleys, that those excavations were very much in their present state when the volcanic eruptions took place.

Valleys in Chalk and Limestone Districts.—When the rocks of any drainage-area are of a kind to be chemically dissolved and removed in solution, the excavation of valleys in them is considerably modified. In limestone districts the hills are commonly either bare or but scantily

* This account of the Moselle valley was given in the last edition, p. 291.

† The volcanoes near Bertrich, such as the Falkenlei and the Facherhue, are really pocket editions, almost cabinet specimens, of volcanoes, the cones not exceeding fifty feet in height, or a hundred yards in diameter at the base.

covered with soil, for the reason already assigned.* They sometimes show, along their ridges, large cavities, called popularly "punch-bowls," sometimes several hundred yards across, and sometimes appearing like winding valleys, closed at both ends. Except while rain is actually falling, very little water may be seen. The joints of the limestone being gradually widened by solution, serve as channels through which the rain at once sinks underground. Part of the water rises here and there, at the base of the hills, in the form of springs; but in many cases a great part flows along in subterranean courses, which have been gradually eaten out of the rock by the solvent power of the water. When these courses are not far beneath the surface their roofs sometimes fall in, and there is then the singular feature of holes in the ground 40 or 50 yards wide, and 50 or 100 feet deep, at the bottom of which the brawling of the underground river may be heard. Good examples of this kind are found in different parts of the great limestone plains of Ireland. "Sometimes the roof of one of the subterranean river-courses has fallen in for some distance along the line of the river, so as to form a narrow rocky valley, from a hundred yards to a mile or two in length. The river comes from under the limestone mass at one end, and runs below it at the other, the rock at either extremity of the fallen-in valley rising like a wall along the face of some strong joint. In the country above and below one of these excavations, no one would have any suspicion of the course or even of the existence of the subterranean river."†

In chalk countries the combined chemical and mechanical action of running water produces similar effects, with this difference, that whereas in tracts of hard limestone the bare rocky sides of the valleys show far-stretching lines of narrow steps and terraces formed by the outcrop of the successive beds of rock, in districts of the softer chalk the surface wastes away into a gently undulating verdurous surface. The absence of running streams on the surface of the coombs and valleys of the chalk countries is no proof of the non-existence of those streams, but only of their subterranean character. There must be as great a rainfall on a chalk country (*ceteris paribus*) as on any of the neighbouring clay or sandstone districts; on the latter, however, the erosion is mainly mechanical and superficial; in the former most of it is chemical, and much of it subterranean, and as the dissolved mineral matter is diffused through the whole bulk of the water, it is carried off as much by the water which rises from below in clear springs, as in that which runs down the surface slopes.

Caverns.—To the solvent action of underground water are to be ascribed the caverns which are found in all large limestone districts. These, like the well-known Mammoth caves in Kentucky, sometimes

* *Ante*, p. 377. † Jukes' MS.

penetrate for many miles in numerous branches, and come from still greater but unknown distances, the farther progress of their explorer being often arrested by underground rivers, with the roof of the cavern sometimes sinking to the surface of the water. These are the points where the subterranean streams are still at work, the dry lofty caverns being the channels they have worn and deserted. The lower parts even of these, however, are in many cases full of water, especially during great floods, which often, as they subside, leave clay sticking to the sides and roofs of the caverns. Bones of land animals may be swept from the surface and buried in the loam of these subterranean rivers. The parts of the caverns deserted by the rivers often become coated and partially filled with stalactite and stalagmite, which is itself an evidence that the water still trickling through the roof of the cavern is dissolving the rocks above it.

Passes or Gaps.—When two valleys among mountains ascend towards each other, there is usually a depression in the ridge, known as a *pass* or *gap*. The origin of this feature is probably to be traced to the gradual lowering, by subaerial denudation, of an original depression in the watershed, and to the manner in which the streams flowing off from that depression would cut their way backward into it. While the general degradation of the mountains was lowering the whole surface, and advancing more rapidly along the depressions, the two streams were eating into their dividing ridge and carrying away its detritus. Hence in the end the ridge would be cut through, and, though the streams would never unite, their valleys might do so, and give rise to one long valley rising up to the watershed on the one side, and descending from it on the other. The junction of the two valleys would then be a *pass*. Subsequent denudation, more especially if the land were depressed and the long valley became a sea-sound, would cut down still more the bottom of the pass, until at last it might become difficult to tell precisely where the original dividing ridge between the two valleys had been. Some remarkable examples of this feature occur among the Silurian uplands of the south of Scotland—a region which has suffered many prolonged denudations, from the times of the Old Red Sandstone downwards.

Fjords.—A fjord has been already described (p. 334) as a submerged land-valley. The west coasts of Scotland and Scandinavia are indented by many such inlets; and as they face the Atlantic it has often been imagined that the indentations have been caused by the breakers of that ocean. When, however, we reflect that the fjords are in many cases of great depth, and that the action of breakers is confined to the surface parts of the sea, we are led to perceive that such long and deep hollows, deeper sometimes than the sea outside of them, could not have been dug out by the action of the sea. They are in fact old land-

valleys, carved out, like other valleys, by the action of subaerial forces, but which, owing to the depression of the land, have sunk below the sea so as to become sea-lochs or fjords. Many of them were once occupied by glaciers, and retain to this day the ice-worn surfaces which were then impressed upon them.*

Lake-basins.—A lake is a cavity on the surface of the land filled with water. When we reflect on the universal waste which is in progress upon that surface, and on the tendency of all running water not to form basins, but to fill them up, we seem at first sight to meet with something exceptional and abnormal in the existence of lakes. Nor is the difficulty lessened when we come to examine the nature and form of lake-basins a little more in detail. If, however, we have fully realised the extent and the results of the denudation which is everywhere going on around us, we recognise the puerility of all those hypotheses which seek to refer the origin of lake-basins to primeval, or geologically very ancient disturbances of the earth's crust. For it is evident that, whatever may have been their origin, their existence cannot but be of comparatively modern date. We see that the streams which enter them push yearly increasing deltas into the water. Every lake in our own country shows this. Many alluvial meadows have evidently at one time been lakes; many lakes have been silted up within the memory of man, many are almost diminishing visibly from year to year. The rate at which mud, sand, and silt, are poured into these hollows shows that the hollows cannot be, in a geological sense, very old. The delta of the Rhone, for example, has crept a mile and a half into the lake of Geneva in about 800 years. Eight centuries, therefore, must represent no insignificant fraction of the interval which has elapsed since the lake first began to receive the detritus of the river. Had the basin been of geologically ancient origin, it must necessarily have been long ago filled up with sediment, and once in that condition, no power of running water could re-excavate it so as to turn it into a lake again.

It is a singular and significant fact, first pointed out by Professor Ramsay, that lakes are scattered in immense numbers over the more northern portions of the globe, while in more temperate and tropical regions they are in comparison rare. These millions of northern lake-basins are for the most part to be found among the oldest stratified formations, in which no trace of recent volcanic action or subterranean movement is to be seen. The palæozoic rocks are crumpled and fractured, but the lakes which lie in them cannot be assigned to the early fractures and convolutions of these ancient rocks, for the aboriginal contour of the surface must long ago have been worn away, and even if the rock-basins could have remained, they must have been filled up with

* See p. 334, *note*, and the authorities there cited; also Geikie, on a Comparison of the Glaciation of the west of Norway and the west of Scotland, *Proc. Roy. Soc. Edin.* for 1866.

sediment, and thus have ceased to hold lakes. Under any allowable explanation, therefore, the facts of denudation make it abundantly clear that all existing lakes must have been formed in late geological periods; so late, indeed, that they may be considered as almost part of the present epoch.

When we come to examine the structure of the lake-basins themselves, apart from theory as to their origin, we find most of them to be in reality hollows worn out of a denuded surface of rock—valleys, whose bottom is below the level of their lower end. Any explanation of their origin must take into account the following facts in their natural history:—

1. Lakes are abundantly scattered over the more northern parts of the globe.
2. They lie in hollows of extensively denuded rocks.
3. They must be of comparatively recent origin.*

Lakes may be grouped into two classes:—1st. Those which are formed by barriers of superficial accumulations; 2d. Those which lie in rock-basins.

I. Lakes dammed up by superficial accumulations. These may originate in at least five ways:—

1. Temporary lakes are sometimes formed where a stream has its waters ponded back by the gravel thrown down at its mouth by the river of which it is a tributary.

2. Landslips, which descend in such mass as to intercept the drainage of the valleys into which they fall, may give rise to lakes, which, unless the impediment gives way, will remain until they are filled up with sediment, or until the streams which escape from them cut their way down through the barrier of rubbish, and the lakes are consequently drained.

3. The moraine of a glacier is sometimes thrown across a valley, and on the retreat of the ice ponds back the water, so as to form a lake. This has happened not unfrequently with terminal moraines, but it may occur also where a lateral valley enters another occupied by a glacier, the ice or its moraine-rubbish serving as a dam to the water.

4. Irregular deposition of loose or detrital materials forms hollows which may eventually hold lakes. This happens (*a*) among moraine mounds; (*b*) sometimes among hills of blown sand when they lie on an impervious bottom; (*c*) among the clays, sands, and gravels of what is called the Glacial Drift, where the detritus has been laid down both on land and on the sea-floor in such an irregular manner as to form many hollows which now serve as lake-basins; (*d*) volcanic cones thrown up close to each other may enclose at their bases hollows which will hold water; (*e*) volcanic craters may be, perhaps, included here: in some

* *Trans. Geol. Soc. Glasgow*, vol. iii. p. 180.

cases, as in the well-known *maare* of the Eifel, they become lakes on the extinction of volcanic activity.

5. Reference may also be made here to the fact, that a stream of lava poured across a valley may form a lake, as has happened at the Lake of Aidat, in Auvergne.*

II. Lakes in Rock-basins.—These are by much the most abundant and important. They differ from those just described, inasmuch as they are due not to mere superficial accumulations impeding the downward flow of the rainfall, but to the formation of actual cavities in the rocks beneath the surface, though the depth of water in them may no doubt be often augmented by barriers of loose detritus placed across their lower lip. There appear to be three processes by which rock-basins may be produced:—1st. By subterranean movements; 2d. By the sinking of the ground, owing to the solution and removal of the rocks underneath; 3d. By the erosive action of glacier ice.

1. From what has already been said, it is evident that if rock-basins are due in any case to the effects of subterranean movements, the latter must have been of late date, and hence that no appeal can be made (as is often, however, done) to aboriginal upheavals and fractures. It is conceivable that lakes may be formed by subsidence, either (*a*) wide-spread, or (*b*) local.

(*a*) The depression of a chain of mountains, until the upper ends of the valleys were thus sunk beneath the level of the lower parts, might turn these valleys into lakes. Sir Charles Lyell† proposed this explanation to account for the larger lakes of the Alps; but, as Professor Ramsay showed, it would require a former elevation of the chain, which is incredible, and even then it would not account for the existence of such lakes as those of Geneva or Neufchatel.‡ The explanation may in some cases be theoretically possible, but it does not seem to have been verified by any actual case in nature.

(*b*) Some lakes may have been formed by special subsidence of their own area. This is perhaps the origin of the great equatorial lakes of Africa, as it undoubtedly is of the Dead Sea and other areas of inland drainage. This explanation, however, is one which it is often difficult satisfactorily to establish, and it is certainly in most cases called in only because no other seems adequate to explain the phenomena. The idea that lakes are formed by synclinal troughs of the strata, or by gaping rents in the earth's crust, arises from inadequate or erroneous conceptions of geological structure and denudation.§

2. When the rocks underneath the surface are of a kind which is easily dissolved and removed by water, subsidence of the ground sometimes takes place. Clays and sandstones, overlying beds of rock-

* Scrope's *Volcanoes of Central France*, 2d ed. p. 92. † *Elements*, 6th ed. p. 170.
‡ Ramsay, *Phil. Mag.* April 1865. § See Ramsay, *Quart. Journ. Geol. Soc.* vol. xviii. p. 152.

salt, sometimes sink gradually down into hollows as the salt is removed from beneath them. In limestone districts, also, this action is to be seen in the way in which, when the roofs of the subterranean caverns fall in and the outlet of the water is choked up, lakes are formed on the surface. Many examples occur "on the lower grounds of the county of Galway and the neighbouring parts of Ireland, where they are called 'turloughs.' Some of them are even a mile or two in length, their flat bottoms being meadows in summer and lakes in winter."*

3. The idea that rock-basins have been scooped out by ice was first started by Professor Ramsay in the year 1859, and has since then been steadily gaining ground among geologists.† He pointed out that lakes are most numerous in northern latitudes where the countries afford evidence of having been once covered thickly with ice, and that they decrease in numbers as we go southwards, away from the ancient ice-fields. He showed, moreover, that the rock-basins lie in denuded hollows, and that their sides and bottom are often covered with the characteristic grooves and striæ graven on the rocks by the ice. Hence there can be no doubt that ice once filled the basins, and not only so, but moved into and out of them. But this could not take place without erosion of the rock; where the rocks were more easily worn down, or where the pressure of the ice was greatest, hollows would necessarily be formed; and on the retirement of the ice, these hollows, unless previously filled up with sediment, would be occupied by water and form lakes. The size and depth of the hollows would depend upon the varying resistance offered by the rocks, the size and slope of the glacier, and the form of the ground. The lakes of the Alps lie in the paths of former great glaciers, and this is true also of the lakes of Wales, Cumberland, Scotland, and Ireland. In Finland, and in Canada, where the lakes occur in thousands, the wonderfully ice-worn aspect of the surface shows that these regions were buried under a great sheet of ice, like that of modern Greenland.‡

That this explanation is the true one for the vast majority of lakes in the northern hemisphere is coming to be gradually perceived even by those who at first were most opposed to it. When we accept its guidance, the apparent anomaly of the existence of deep hollows on a land surface, undergoing constant denudation, is removed. For we see that, in place of being abnormal, these hollows are themselves but proof of one of the many ways in which the land is worn away.§

* MS. note by Mr. Jukes.

† See "The Old Glaciers of Wales," in *Peaks, Passes, and Glaciers*, 1st series, published afterwards in a separate work; also his great paper "On the Glacial origin of certain Lakes in Switzerland, &c," *Quart. Jour. Geol. Soc.*, xviii. p. 185.

‡ See *ante*, p. 409.

§ There is a rather voluminous literature on this subject. The few following references may guide the student:—(1.) *Supporters of the theory of underground movements*:—Murchison,

2. Plains and Table-lands.

Plains may be said to be of two kinds—Plains of Denudation and Plains of Formation.

Plains of Formation, properly, are those beneath which the rocks not only retain their original horizontality, but the surface of which is the surface of the last bed that was formed there. Deltas and alluvial flats of rivers are almost the only places where these conditions are fulfilled to the letter. The term, however, may be extended to include flat areas at any elevation above the sea, from which no considerable thickness of beds has ever been removed. The surface of the Desert of Sahara may be such a plain, as also those of the interior of Australia, of the Pampas of South America, of large tracts in the northern part of Siberia, of much of Poland and the adjacent parts of Europe, and even the flat lands along the eastern coast of England, and some of those of Central France. It is, however, very doubtful in many of these cases what is the actual amount of matter which has been removed from off the present surface.

Plains of Denudation are those where a horizontal surface has been worn out of rocks by denudation, irrespective altogether of their inclination, fractures, curvings, or other geological characters. Such plains appear necessarily to be of marine origin, since they may be regarded as the former downward limit of the denudation of a country which had been previously wasted by subaerial and marine action.* The limestone plains of the interior of Ireland are good instances of this case, since they were obviously once covered by a vast thickness of Coal-measures. The New Red Sandstone plains of England were in like manner formerly covered by the Lias at least, if not more or less completely by the Oolites, and even much of the chalk. Whenever outlying hills or basins of superior rocks are scattered over such plains, the denudation of the intervening portions may be fairly assumed to have occurred, and therefore that the surface of the plains themselves is one that has been exposed by the removal of its former cover.

Table-lands.—When a plain of denudation is elevated to a height of several thousand feet above the sea, so as to form a great inland high-lying area of tolerably level or undulating ground, it is called a table-land. It is evident, however, that no such area could be raised

Proc. Geograph. Soc. for 1864. J. Ball, *Phil. Mag.* 1863, p. 81. Desor, *Revue Suisse*, 1860. *Gebirgsbau der Alpen*, 1865, p. 118 *et seq.* Lyell, *Antiquity of Man*, p. 316; *Elements*, p. 170. Studer, *Archives des Sciences Phys. et Natur.* tome xix. (1863). Favre, *Phil. Mag.*, March 1865. (2.) *Supporters of the ice-erosion theory*:—Ramsay, in the papers already cited. Jukes, *Reader*, 12th March 1864. Geikie, *Trans. Geol. Soc. Glasgow*, vol. i. (1863), p. 86; and iii. (1868), p. 180. Belt, *Quart. Jour. Geol. Soc.* xx. p. 463; Haast, *Op. cit.* xxi. p. 130.—Consult also Rutimeyer's *Thal-und See-Bildung*, 1869, p. 79 *et seq.*

* See *ante*, p. 438.

into that position without beginning to suffer from subaerial denudation.* The more ancient the table-land, the more would it be denuded, until in the end it might become difficult, if not impossible, to recognise the traces of the original plain, the whole area having been converted into one of wide valleys and deep gorges, with lofty hills and mountains between them. Examples may be found in different parts of the world of the various stages in this process of the denudation and gradual destruction of the characteristic features of a table-land. In Scandinavia, for example, the great mass of high ground which runs northward along the whole extent of Norway is an ancient table-land carved out of highly-inclined contorted and metamorphosed palæozoic rocks. But subaerial denudation has been at work upon it so long, that it is cut up in all directions by glens and fjords. Yet large fragments of the old flat surface remain, and are known as *fjeld*, as in the well-known Dovre-fjeld, and in those which serve as the great snow-plains from which the Norwegian glaciers descend. And even where the ground has been cut up most into fjords and valleys, we find on ascending to the tops of the intervening ridges that the summits of the hills undulate up to the same average level—that level representing approximately the original surface of the table-land, before the excavation of the valleys and consequent isolation of the ridges and hills.† In Wales and in Scotland the same average height among the Silurian mountains is found associated with strips and fragments of the old table-land or *fjeld* out of which these mountains have been carved.‡

3. Mountains and Hills.

Properly to understand the history of the origin of the form of a hill or mountain, it is necessary to understand first of all the geological structure of the eminence. If this precaution had always been taken, the literature of geology would have been saved from much profitless and even absurd disquisition. It is not enough, however, that we should study the structure of the rocks; we must at the same time trace out the effects of denudation upon them. Only by this combined study of external and internal features can we hope, with any approach to certainty, to unravel the often complicated history of mountains.

Relation between External Form and Internal Structure.—The fact that mountains are frequently found to be formed of crystalline,

* That is, of course, if the elevated area were one subject to the action of rain, snow, glaciers, or rivers.

† It need hardly be pointed out that, as subaerial denudation has affected the tops of the ridges and the surface of the fjelds, as well as the sides and bottoms of the valleys, the existing hill-tops and fragments of the old plateau can only approximately represent the level of the old table-land.

‡ See Ramsay's *Phys. Geog. Brit.*, lect. iii.; and Geikie's *Scenery of Scotland*, chaps. v. vi. and ix.

contorted and fractured strata, has been a fruitful source of misconception and error, because observers, dwelling upon that striking feature, have neglected the other, but not less marked, aspect of mountains—their proofs of enormous denudation. Appeals are often made to mountainous tracts of crumpled, broken rocks, as retaining in great measure, on their still existing surface, the "aboriginal outline" impressed upon it by ancient upheavals and fractures. The Scottish Highlands, for example, are cited in illustration of this supposed relationship of external form to internal structure. Yet a little reflection should suffice to show that the relationship must be wholly illusory. In the case of the Scottish Highlands, for instance, it can be demonstrated, by the simplest kind of geological reasoning, that the crumpling of the gneiss and schist must have happened previous to the formation of the Old Red Sandstone. If, then, the present features of the surface had been due to the crumpling and fracture of the rocks, they must date from a time anterior to the Old Red Sandstone. It would follow, either that the time during which the Old Red Sandstone was accumulated could not be removed by any long period from our own day, for otherwise the original outlines of the surface would have been obliterated by atmospheric waste, acting even no faster than it is doing now; or that the rate of denudation (and consequently of deposition) must have been in past time indefinitely slower than at present. Both these suppositions go in the face of all received geological belief.

But what is true of the Scottish Highlands is equally so of other districts where ancient metamorphic rocks rise into rugged outlines at the surface. If such outlines had been produced so long ago as the time of the Old Red Sandstone or Silurian formations, it is clear that, in the interval which has since elapsed, the common forces of denudation must have been wholly, or almost wholly, inoperative. Had these forces acted even in the feeblest manner conceivable, it is incredible that any vestige of a land-surface should have retained its original contour during the lapse of all the ages which have passed away since the middle of the palæozoic period. But we have only to look at the vast thickness of stratified rocks deposited during these ages, to see that the forces of denudation were far from idle; that, on the contrary, they were probably at least as active, on the whole, as they are now. Hence we are shut up to the conclusion that if the crumpling and fracturing of the crust of the earth during palæozoic times gave rise to broken and rugged land-surfaces, such surfaces could not withstand the ordinary wear and tear of the common denuding agents, but must long ago have been effaced.*

If we reflect still further on the general geological structure of mountains, we are led to perceive that, in the great foldings into which

* *Trans. Geol. Soc. Glasgow*, vol. iii. p. 177.

the strata have been thrown, the depth to which any given set of beds must descend into the earth is vastly greater than the height which the same beds ever reach above the sea-level.* There can be no reason for this difference except in the fact that in the downward curves the beds remain preserved in the earth, while in the uplifted parts the rocks have been brought within the influences of denudation, and hence that our hills and mountains are but the ruined fragments of the mass of rocks which once existed. The following illustration, from the geology of Wales, will make this line of argument clear.

"The Silurian rocks of Wales have been thrown into great folds, which can be traced out, and have been shown in the maps and sections of the Geological Survey. Their nature is indicated in Fig. 141, which has been suggested by the Survey sections.† The summit of Snowdon rises over the centre of a synclinal trough, from underneath which the lower beds rise steeply all the way to the Menai Straits and into Anglesea. The peak of the mountain, therefore, stands in the centre of an area of comparative depression, while the greatest movement of elevation, that which has brought the most deeply-seated rocks up above the sea-level, is in the part where there is comparatively low land on each side of the Menai Straits. The thickness of rock that 'takes the ground' between the Menai Straits and the summit of Snowdon amounts to many thousands of feet, and all that thickness must once have extended across the Menai Straits and all over Anglesea, as indicated by the dotted lines in the figure. That it really did so extend is proved by some of the beds being brought in here and there, wherever there occur faults with sufficient downthrows, or troughs with sufficient curvatures, to bring them in below the level of the present surface of the ground.

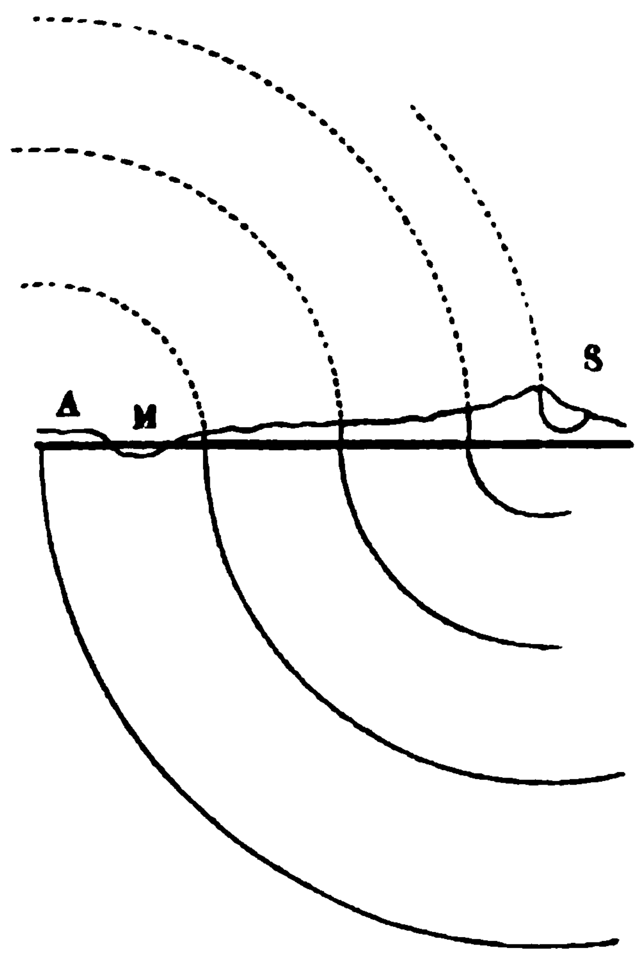

Fig. 141.

Diagram-section from Anglesea to Snowdon.

In this Fig. S represents Snowdon; M, the Menai Straits; and A, Anglesea. The downward curves indicate the position of the rock below the present surface; the upward dotted curves show the former extension of those removed by denudation.

"These statements may be extended to the whole of N. Wales, from underneath which these lowermost rocks rise in several detached areas. It is remarkable that in no case where these deeply-seated rocks are raised to such an altitude above the sea is the surface of the ground now existing over them higher than other ground in the neighbourhood. This shows that a great internal movement of elevation is not necessarily marked by correspondingly high ground. It is equally remarkable that all the highest

* See Hopkins, "Presidential Address," *Quart. Journ. Geol. Soc.*, ix. p. lxiii.

† See Professor Ramsay's "Memoir on N. Wales," *Mem. Geological Survey*, vol. iii.

hills in Wales rise over points which have not been affected by the greatest movement of elevation, since much more deeply-seated rocks rise from beneath their bases, up to the surface of the ground, on one side or other of them."*

An inspection of any section upon which the geological structure of a mountainous region is depicted, with even an approach to accuracy, will almost invariably show at once that no general connection can be traced between the external shape of the surface of the ground and the movements which have taken place among the rocks below it, and that any effect such movements may have produced upon the surface, which existed at the time of their occurrence, has had comparatively little influence on the form of the present surface, for it can almost always be shown that a vast thickness of rock has been removed since those movements altogether ceased, and that our present land-surfaces are the result of that denudation.

"It is important also to bear in mind that the internal movements of disturbance have definite periods of occurrence, while those of denudation can never cease to act upon any mass of rock which is above the level of the sea. Denuding action is at work on the British Islands perhaps with as great an intensity as ever it ordinarily has been, but no perceptible internal movement is going on; and it can be shown that the great dislocations affecting our mountains ceased in early geological periods, and have not since been renewed in any appreciable degree. At the same time the geologist must recollect that by far the greater part of the denudation of the older rocks is itself of very ancient geological date. It is clear, for instance, that some of the lowest rocks of North Wales (those called Cambrian) had been laid bare before the Carboniferous rocks were formed. In Ireland, also, we get Carboniferous limestone resting on the Cambrian rocks at Taghmore, and near the town of Wexford; and the Leinster granite was exposed before that period by the removal of all the Silurian slates that must have originally covered it. The amount of erosion and denudation which took place during the Palæozoic periods was enormous. Geologists are apt sometimes to forget this, and to assign all the results of this ancient action to comparatively recent times."*

While the great fact remains that the present surface of our islands and continents is a sculptured surface, variously carved out by the denuding forces, we are not to suppose that underground movements have had no influence upon the ultimate form which that surface has assumed. This influence, however, must, it is clear, be of a very different kind from the influence popularly attributed to these movements. Its nature will be best understood if we classify and describe hills according to their mode of origin, as, 1st, Hills of Accumulation*; 2d, Hills of Upheaval; 3d, Hills of Circumdenudation.

1. **Hills of Accumulation.**—These have been formed by the piling up of materials upon the surface of the ground. The agents by which such hills can be formed are few in number, and consequently the hills themselves form but a mere fraction of the total number of hills on the earth's surface. Hills of accumulation are the only hills originally formed, as such, with an approximation to their present outlines, though even they are no sooner formed than they begin to be altered by denudation. The most important are volcanoes—conical piles of ashes and lava poured out from beneath, and rising on mountain-chains to heights of sometimes 20,000 feet above the sea. The conical shape of

* MS. notes by Mr. Jukes.

a volcano is due to the effusion of material round a central orifice, and its size and height to the quantity of material which has been thence ejected.* Minor hills and ridges are formed by the action of the wind upon loose drifting sand,† and still smaller eminences of shingle are sometimes raised by the breakers along a coast-line.‡

2. Hills of Upheaval.—All dry land is due primarily to the upheaval of the sea-bed. Some portions have been raised more than others. Out of such portions most of the mountain-chains of the globe have been formed. But it is seldom, if ever, that the inequalities of the original surface of upheaval remain as the inequalities of the existing land-surface. Even where a mountain-slope corresponds with the exposed surface of a bed of rock, it can almost always be shown that this surface at the time of upheaval was covered with other rock now removed. Some remarkable examples of the coincidence of lines of anticlinal axis with lines of elevated ridges occur in the Jura. The drawings usually given of that structure, however, convey an erroneous impression that the present contour remains very much as it was left by the subterranean movements. But if we examine the ground with even moderate attention, we soon find proof that, though it is there undoubtedly true that the ridges are formed of anticlinal and the valleys of synclinal folds, there has yet been a vast deal of denudation in progress over the surface since the date of the contortions. The subjoined figure represents

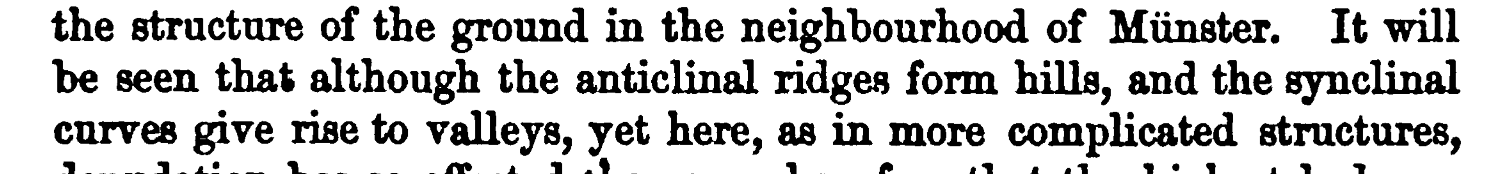

Fig. 142.

Diagram-section of anticlinal and synclinal folds of Upper, Middle, and Lower Jurassic rocks, forming hills and valleys in the Jura.

the structure of the ground in the neighbourhood of Münster. It will be seen that although the anticlinal ridges form hills, and the synclinal curves give rise to valleys, yet here, as in more complicated structures, denudation has so affected the general surface that the highest beds are found in the valleys and the lowest on the hill-tops.

The simple structure of the Jura Mountains is of rare occurrence in nature.§ Most mountain-chains consist of many complicated lines of anticlinal and synclinal folds, broken through by faults, and the rocks are often not merely folded but violently crumpled and metamorphosed. A mountain-chain may be composed of many subordinate ranges, and while the general direction of the folds of the rocks will coincide with that of the chain, there may be endless local diversities between them.

* See *ante*, Chap. XIX. p. 345. † See *ante*, p. 378. ‡ See *ante*, p. 415.

§ See by way of comparison the somewhat analogous structure of the Appalachians, as shown in the maps and sections of Roger's *Pennsylvanian Survey;* also in Keith Johnston's *Physical Atlas*, and in J. P. Leslie's *Coal and its Topography*.

The coincidence is more usually to be observed in the great folds. The curves of minor flexure may set in both lengthwise and laterally, since the axis over which the greater anticlinal and synclinal curves are bent, often undulates so as to allow anticlinal and synclinal folds to pass into each other.

Except the coincidence in general linear direction, the external features have no *necessary* connection with the internal curves of the rocks. A chain formed of several parallel ranges may have only one anticlinal fold, the parallel ranges and longitudinal valleys being formed on the outcrop of parallel groups of beds of variable rates of destructibility. A chain of complicated internal structure may have a simple external outline, or one of great internal simplicity of structure may have a most broken and complicated outline, these variations being largely due to the varying resistance presented by the different rocks to the progress of denudation. The axis of a synclinal trough is frequently marked by an external ridge ; while, on the other hand, a deep valley runs along the crest of an anticlinal saddle. This is precisely the reverse of what ought to be the contour of the ground if the latter were due directly to underground movements. That which, in geological structure, should be a mountain, is found to be a valley, and what might be expected to form a valley rises up as a hill or mountain. In endeavouring to account for this feature, we may suppose that in some cases, at least, there was an actual longitudinal fracture produced by the great tension of the rocks along the crest of the anticlinal fold, and that this fracture was subsequently widened by denudation into a valley. It is highly probable, however, that in a great many instances the folds were not formed suddenly, but very slowly—so slowly, perhaps, that the tops of the anticlinal ridges were worn down by denudation as fast as they rose, more especially if the strata first removed were underlaid by others possessing less power of resistance. It is evident, also, that the strata of an anticlinal ridge, sloping with its slopes, would be much more likely to break up and slip down the incline in fragments than where, as in a synclinal trough, they dipped inward from the surface and presented merely their edges to denudation. The tendency of rocks, curved into basins, to resist denudation better than in anticlinal curves, and thus to form hills, while the latter sink into valleys, may be recognised not only among comparatively little disturbed tertiary and secondary formations, but even among contorted and metamorphosed schists.*

While there is thus no general coincidence between the anticlinal and synclinal curves and the surface-slopes, there is equally little between the contortions of the rocks and the irregularities of the surface. It requires only a moment's reflection to perceive that the mere existence of crumpled and contorted rocks at the surface is a proof of

* See Topley, *Geol. Mag.*, iii. p. 438, and the authorities cited by him.

enormous denudation, and consequently of the disappearance of the original surface. The well-known contortions so wonderfully exhibited along the mountainous sides of the Lake of the Four Cantons, while they afford memorable evidence of the enormous plication of the rocks which attended the elevation of the Alps, show also that the present surface of the mountains has only been attained after the removal of an enormous mass of rock which existed when the rocks were contorted.

In hills of upheaval, then, we must regard the function of the underground forces to have consisted mainly in the elevation of the mass of high ground, and the production of its geological structure, simple or complex as that may be. The subsequent sculpturing of this mass of high ground into peak and crest, mountain and valley, lake and ravine, has been the work of denudation. In Fig. 143 a section is

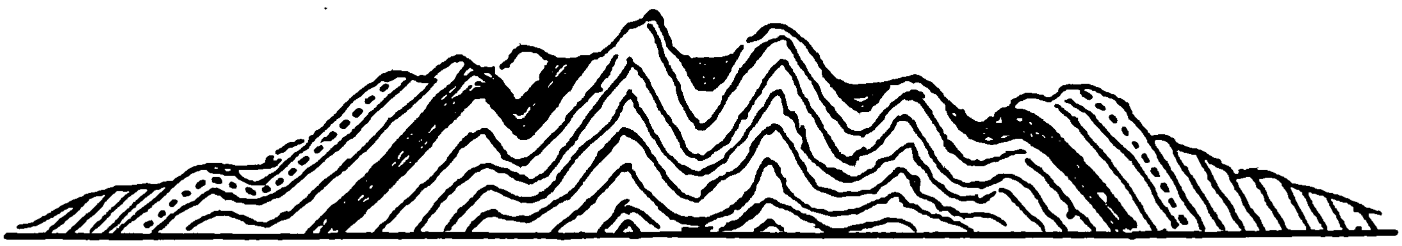

Fig. 143.
Hills of upheaval.

given across a supposed mountain range formed out of one large anticlinal fold, with minor curves along its crest. In this illustration we see that, as before, the lowest beds which come to the surface are those of the hill-tops, while the beds which are highest in geological position lie at the lowest levels, and slope away from the range to the plains below. This is, in a general way, the structure of most great mountain-chains, and it shows how the underground and surface agencies combine to produce some of the most marked features on the surface of the globe.

The elevation of a mountain-chain has sometimes taken place not in one continuous movement, but at intervals. This is shown by the successive unconformable junctions of the rocks of which it is composed. From these junctions, too, we learn that the intervals were employed in the denudation of the previously-tilted rocks, and the formation of new rocks out of their debris. In Fig. 144, for example, the central

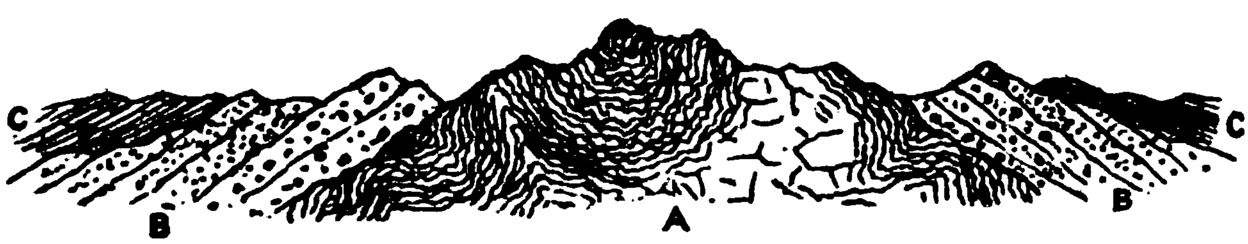

Fig. 144.
Section of a mountain-chain, indicating three periods of upheaval.

group (A) of crumpled metamorphosed rocks and granite was upheaved and denuded before the deposition of the series B; the latter was tilted

and worn away before the third group (C) was laid down, while that group has in turn been elevated and denuded. In this chain, therefore, we have evidence of three successive movements, and of a long process of denudation which has been going on ever since the first ridge of the range rose above the sea.

The occurrence of igneous rock among the uptilted aqueous ones will of course produce its effect on the form of the surface over it, but it is an indirect effect, due to the difference of denuding action upon rocks of different composition and structure. If the igneous rock resist that action better than the surrounding aqueous rocks, it will stand out prominently above the surrounding surface; if it yield more readily, it will form a flat or a hollow. The igneous rocks which occur in the central parts of mountain-chains are usually associated with evidences of great contortion and metamorphism. They must be regarded as of deep-seated origin, and their presence now at the surface must be held to be additional evidence of the great denudation of the mountain-ranges in which they are found.

The occurrence of ancient volcanic rocks in a mountain or chain may produce considerable diversity of external form. This never arises, however, from the original superficial contour which these rocks assumed at the time of ejection, but in all cases is the result of denudation. The volcanic rocks imbedded among the other geological formations have shared in all the foldings and fractures which these formations have suffered; and if they now rise into bold crags and mountains, it is because their compact texture has enabled them better to withstand the attacks of the denuding forces which have worn away the other and softer rocks.

Where modern volcanic rocks occur in a mountain-chain, as in the Andes, they give rise to the characteristic forms of hills of accumulation. But they are at once attacked by the denuding agents, and unless from time to time renewed by the ejection of fresh volcanic materials, they come in the end to be unequally worn away, according to their varying powers of resistance, just as all other rocks do.

3. **Hills of Circumdenudation.**—While the class of hills just described owes its mass and linear direction to the upheaval of a strip of the earth's crust, there is another class in which the mass and direction have been determined by surface action. These may be termed Hills of Circumdenudation.* They are fragments which have been left in the denudation of a mass of high ground. Between this form of hill and table-lands, there is the closest connection. When a table-land begins to be furrowed by streams, and gradually carved out into valley-systems, the spaces of higher ground between the valleys rise up as hills of circumdenudation. The denudation may go on until the form

* This term was used by Mr. Jukes in the previous edition of this Work.

of the original table-land is lost, and in its stead there appears a system or systems of valleys, with wavy, irregular mountain-ridges between them.

In this prolonged process of denudation the influence of the geological structure of the rocks is not unimportant. While the harder masses will always tend to form hills, and the softer rocks are worn into valleys, the position of anticlinal and synclinal curves, alternations of variously-composed strata, faults, and other features, may serve to guide the course of the denuding agents.

The simplest form of a hill of this kind is furnished to us by one of the outliers so abundant along the edge or escarpment of the secondary strata of England. In Fig. 134, p. 439, the outlier B is a hill of circumdenudation formed by the destruction of the table-land, which has its front or escarpment at A. The strata may either be very gently inclined, as in that figure, or they may be quite horizontal or curved, as in Fig. 145. When, however, we come to examine some of the

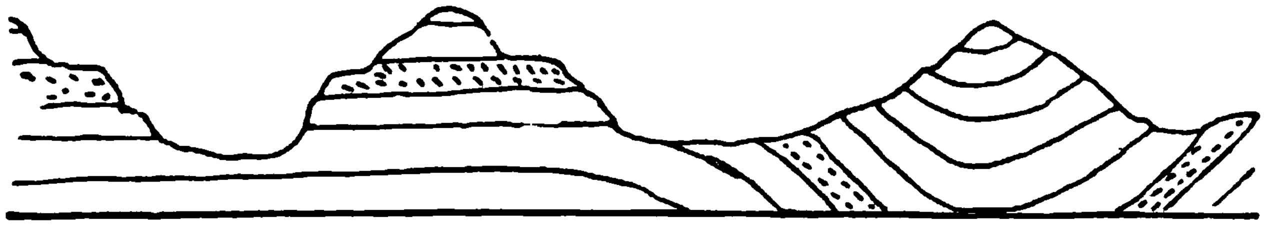

Fig. 145.
Hills of circumdenudation, formed of horizontal and curved strata.

ancient table-lands of palæozoic rocks, we find the strata composing them to be violently contorted, and often quite vertical (Fig. 146). In

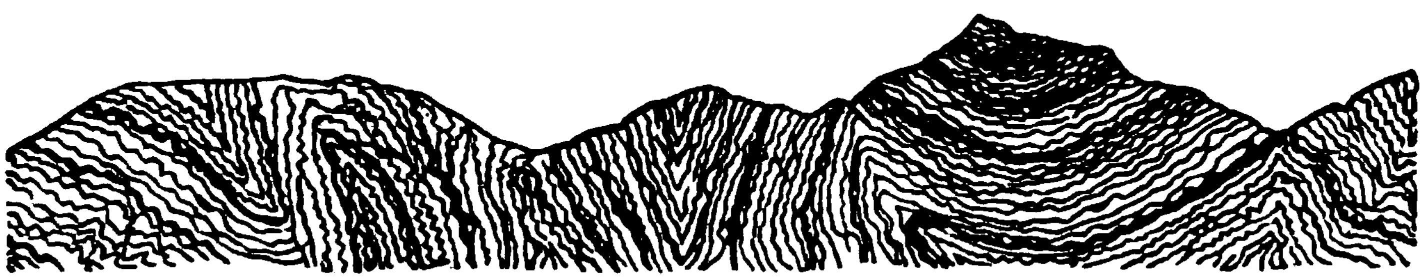

Fig. 146.
Hills of circumdenudation and fragment of table-land, formed of contorted and foliated rocks.

Scandinavia, for example, the rocks are of this kind, and the table-land formed of them has been deeply trenched by valleys and fjords, and turned into branching ridges of denuded mountains. In Wales, the Lake country, and in the Southern Uplands and the Highlands of Scotland, we see other illustrations of ancient plains or table-lands of contorted palæozoic rocks, which have been so sculptured by the denudation of their valley-systems as to be turned into connected groups of hills and ridges of circumdenudation.

Influence of the Weathering of Rocks upon Mountain Outlines.—While the external forms of hills are often largely determined by

geological structure, the variations in the modes of weathering of the rocks give rise to endless diversities of minor features. Each well-marked variety of rock has its own style of weathering, and consequently its characteristic scenery. Those rocks which occur in thick horizontal or gently-inclined beds, such for example as limestones, sandstones, and some forms of trappean rocks, often form terraced hills, the terraces being due to the edges or outcrops of the successive beds. A thick bed or series of beds, of comparatively hard rock, resting upon softer strata, gives rise to an escarpment. Unstratified rocks, with no very definite divisional planes, form conical mountains, as is the case with many porphyries. Rocks which weather rapidly along the joints and outer surface, as granite so frequently does, give rise to *tors*, pinnacles, and rocking-stones. Lines of bedding, cleavage, or foliation, among hard altered strata, are often revealed by the serrated outline which they produce along the bare crests of the ridges and peaks.*

Origin of Escarpments.—An escarpment is a cliff or precipitous bank formed by the outcrop of a bed or series of beds of harder consistency than those on which they rest. It only occurs where the strata are not steeply inclined, or are horizontal. When the inclination rises to a high angle, the outcrop of the harder beds may form a ridge at the surface, but not an escarpment. The reason of this appears to be that the escarpment-face tends to coincide with the larger joints, and thus to rise at a right angle to the dip. If the wasting of the rock were uniform over its exposed surface, and if the weathered portion were removed as soon as detached, the escarpment would be perpendicular to the plane of dip. If in this case the beds were horizontal, the escarpment would of course be vertical; if they dipped at 10° the face of the escarpment would measure 80°; at a dip of 20° the cliff would rise at an angle of 70°. So that the farther the dip of the strata deviated from the horizontal, the farther would the face of the escarpment depart from verticality. But in actual fact we seldom find this ratio to hold very strictly, for the upper parts of the cliff, being exposed both above and on their steep face to denudation, are worn away faster than the lower parts, while these are further protected by the ruins of the cliff gathering over them. Hence escarpments are usually blunted, and not so steep as we might at first expect them to be. The steepest are those which are formed by the outcrop of horizontal beds, where the detritus which falls from the cliffs is rapidly disintegrated and removed.

Escarpments, depending as they do on the outcrops of strata, follow the course of these outcrops, and wind about with them. They thus

* See Mr. Ruskin's *Modern Painters*, vol. iv., for eloquent disquisitions on mountain-form and mountain-structure. The student may also be referred to the Editor's *Scenery of Scotland*, chap. viii.

often resemble long lines of old sea-cliff, and their trend inland has frequently been described as that of ancient sea-margins. But though there is a general resemblance to sea-cliffs, it disappears on closer examination. An escarpment keeps to the outcrop of the bed or beds of which it is formed, while a sea-cliff does so only now and then, when the outcrop happens to come to the shore. A sea-cliff has its base at an uniform height, corresponding to the limit of breaker-action, while an escarpment rises and falls with the change of dip of its component strata, sometimes rising continuously for a long way, till its base at one part attains a much higher level than its summit at another. These and other differences serve to indicate that escarpments are not of marine origin, but due to subaerial denudation. The cliff exists because the rock of which it is composed is harder than the rocks below it; and we see it worn away still by the same agency. Springs and frosts split up the rock or loosen it, and allow it to be washed away by rain. Every fresh removal allows a fresh surface to be exposed, and as the detritus, after protecting the base of the escarpment for a while, is eventually removed, slice after slice is cut away from the outcrop of the bed, and the escarpment recedes across the country. The process will continue as long as the harder bed remains above the sea-level, or until, in the course of the recession of the cliff, some fault is reached by which the harder bed has been depressed beneath the surface, or elevated so as to have been removed by an earlier denudation.*

* See Topley, *Geol. Mag.* vol. iii. p. 436; and Whitaker, *Op. cit.* vol. iv. p. 490.

III. PALÆONTOLOGY.

CHAPTER XXVII.

ZOOLOGY AND BOTANY.

Nature of Fossils.—Palæontology* is the study of "fossils." The old geologists used to include minerals or any other distinct bodies that were found in rocks under the term "fossils." By "a fossil," however, is now meant the body, or any portion of the body, of an animal or plant buried in the earth by natural causes, or any recognisable impression or trace of such a body or part of a body. "Fossils," then, are "organic remains," including under the word "remains" even footprints, or other such seemingly transient impressions, which circumstances have rendered permanent. MM. D'Orbigny and Pictet introduce into their definitions of the word "fossil" the time when and the circumstances under which this burial took place. It appears to me that this is not necessary. Nobody would say that shells lately thrown up on the beach, and covered with sand, were *buried in the earth*, while every accumulation of shells, or bones, or plants, which could be said to be *buried in the earth* by any other than human agency, even if that burial took place last year, would be well worthy of the attention of the Palæontologist, and might be, without impropriety, spoken of as *fossil*. Here, as elsewhere, no hard line can be drawn between the present and the past. All such terms, then, as *sub-fossil*, which we sometimes meet with, are inconvenient and unnecessary.

Neither should we include, in a definition of a "fossil," any reference to its present state. Some fossil shells found in comparatively old rocks, such as the soft compact clays of the Oolitic series, are in fact less altered from their living state than many shells included in recent coral reefs. Wood again may be found in such rocks still soft and but little altered, while in much more recent formations it is often entirely mineralised, and converted either into coal or flint, or sometimes limestone.

* From παλαιός, *palaios*, ancient; οντα, *onta*, beings; λογος, *logos*, a discourse; a discourse about ancient beings.

Any substances firmly buried in clay, not impregnated by any active mineralising agent, and not admitting the passage of air or water, may remain unaltered for an almost indefinite period. In the majority of instances, however, the enclosing rock has either itself contained some active substance, or has given passage to water containing one ; or again, the constituents of the enclosed body itself have acted on each other, or on those of the surrounding rock, and thus the fossil has become more or less mineralised, or *petrified* as it is called. We have seen previously * that rocks themselves undergo great alteration in their internal structure in the course of time, and that minerals are changed or metamorphosed *in situ* from one into another by the gradual action of chemical forces. Fragments of animals and plants, dead, and therefore subject to the *mineral* laws, as they might be called, and not to the laws of life, must of course be subject to the same actions as the mineral constituents of rocks.

The hard parts of animals, such as bones, shells, crusts, and corals, are composed principally of those mineral substances (salts of lime, etc.), which are most easily acted on by the most frequently occurring chemical processes. In breaking open fragments of coral lying on a coral reef, the internal parts are very frequently found to be filled with a mass of crystalline carbonate of lime, obliterating or obscuring the organic structure. A recently-raised coral reef, composed wholly of organic fragments, often shows to a cursory view no more trace of its organic origin than one of our crystalline limestones of great geological antiquity.† When shells or corals are imbedded in any rock percolated by water, it is almost impossible for them to escape that partial re-arrangement of their particles which gives them an internal crystalline structure. The alteration may go on until every original particle has been replaced by another, what was once carbonate or phosphate of lime being in the end replaced by silica, pyrites, or some other mineral.‡

Still, as this conversion is a molecular one, taking place only in the ultimate particles of the substances, the organic structure is often perfectly preserved during petrifaction, the little internal pores or cells retaining their form so completely as to be recognised by the microscope. It is as if a house were gradually rebuilt, brick by brick, or stone by stone, a brick or a stone of a different kind having been substituted for each of the former ones, while the shape and size of the house, the form and arrangement of its rooms, passages, and closets, and even the number and shape of the bricks and stones, remained unaltered. The hollow spaces, however, in the interior of a fossil, are usually filled up either by the substance of the rock in which it lies, which has gained access to the interior through natural openings or

* Page 360 *et seq.* † See *ante*, p. 388. ‡ See *ante*, p. 361.

accidental fractures; or else by crystalline minerals, the dissolved constituents of which have percolated through the pores of the walls surrounding the hollow spaces, just as they do into any other cavities in rocks.

It sometimes also happens that the substance of the fossil has been altogether removed, and merely its "mould" or impression left in the rock that enclosed it. This mould or *external cast*, in some instances when the original body was a hollow one, also encloses an *internal cast* consisting of the matter which gained access to the interior of the fossil.

Sometimes the fossil is very distinct, and can be completely detached from the matrix or rock in which it is enclosed. Sometimes, on the other hand, it is so intimately united with the matrix, and so blended with the substance of the rock, that we can only observe a section of it when the rock is broken open. Sometimes the fractured surface of the rock must be polished before we can distinguish the structure or even the outline of the fossil, and sometimes the rock has to be cut into slices so thin as to be transparent before the microscopical examination can be applied to them.

Palæontological Requirements.—It is obvious that we must have some knowledge of existing animals and plants, in order rightly to understand the facts of palæontology. Fossil animals and plants are either of the same species as those now living, or of different species. In order to ascertain which of these is true, we must necessarily know the living species when we see them. Whether the species of fossils be living or extinct, in order to draw any conclusions respecting them, as to the place where they lived, for instance, and the circumstances under which they were buried, we ought to know the habits of the living species with which they are identical, or to which they are most nearly allied.

No man can become a palæontologist who is not also a biologist (zoologist or botanist); and no man can become a thorough zoologist who has not had that early training in anatomy which usually falls to the lot of the medical student only. To become a thorough palæontologist, a man should have what is called a medical education. But it is quite possible, even without this training, to master at least some particular branch of the subject. For the purposes of geological study, a certain amount of acquaintance with palæontology, and therefore with zoology and botany, is needed. In the Appendix to the present volume the student will find a systematic arrangement of the animal and vegetable kingdoms; and in this and the following Chapter some observations are offered for his guidance in the general principles of palæontology.

Distribution of Animals and Plants.—Every one is doubtless ac-

quainted with the fact that the individuals of the different species of animals and plants are not indiscriminately scattered about the earth. Palm-trees, bananas, and pine-apples, do not grow in the open air in temperate zones ; nor apples, barley, or potatoes, on the low lands of the tropics. The polar bear and the lion, the reindeer and the camel, the musk-ox and the giraffe, do not inhabit the same regions. If we ask why these different species do not live beyond certain limits, we learn that *a climate different from that in which they now live would not be suitable to them.* We arrive then, first of all, at the conclusion that the limitation of species depends upon variations in climate; that is to say, upon the physical conditions of different regions.

This restriction of certain species to particular areas, by the action of surrounding circumstances, however, gives us no explanation of a still more remarkable phenomenon in the distribution of species, which is, that in different parts of the earth which have climates essentially alike, the species of animals and plants are often very different. There is, for instance, a much greater difference in the species of animals and plants native to the borders of Europe and Asia, and those living in corresponding latitudes in the centre of North America, than there is between the climates of the two regions. In like manner, the animals and plants native to South America, South Africa, and Australia, differ far more from each other than do the climates of those countries. We may speak of this distribution of species as the result of *sporadic* (or scattered) *origin.* It will be necessary to devote a little space to the examination of the principal facts connected with these two kinds of distribution.

Land and Ocean Climates.—If we ascended from the level of the sea near the equator, up the sides of a lofty mountain to the regions of perpetual snow, we should pass in a few miles through the same variations in climate as if we travelled along the sea-level to the arctic or antarctic circles. The variation in the species of animals and plants would also be similar in the two journeys. The difference, indeed, would be chiefly in the rate of change—hundreds of feet vertically, producing an effect equal to that caused by hundreds of miles laterally.

Meyen makes eight vertical botanical regions under the equator, as follows :—

		Height in Feet.
	Region of perpetual snow, with no plants	16,200
1.	Region of Alpine Plants	14,170
2.	Region of Rhododendrons	12,150
3.	Region of Pines	10,140
4.	Region of European Dicotyledonous trees	8,100
5.	Region of Evergreen Dicotyledonous trees	6,120
6.	Region of Myrtles and Laurels	4,050
7.	Region of Tree-Ferns and Figs	2,020
8.	Region of Palms and Bananas	0

As each of these vertical regions ranges north and south, it descends towards the level of the sea, and forms a zone surrounding the earth; the eighth region forming the equatorial zone, 15° broad on each side of the equator; the seventh, the two tropical zones, each 8° broad; the sixth, the two subtropical, 11° broad; the fifth, the warmer temperate zones, 11° broad; the fourth, the colder temperate zones, 13° broad; the third, the subarctic zones, 8° broad; the second, the arctic, 12° broad; and the first, the polar zones, 10° broad, terminating in lat. 82°, the spaces between that parallel and the poles representing the ice-caps or regions of perpetual snow, in which vegetation is impossible. These zones are bounded, however, by isothermal lines, rather than parallels of latitude, so that the width of some of them varies in different parts.

A similar change of climate takes place as we descend vertically into the sea, and a similar consequent change in the species of animals and plants. This was first clearly shown by Edward Forbes, during his researches in the Ægean Sea. He divided all seas into five vertical spaces, which he called zones (not regions), as follows:—

1. Littoral zone, the space between high and low water-mark, or where there is no tide, the water's edge.
2. The circum-littoral zone, from low-water mark down to about 15 fathoms.
3. The median zone, from 15 to about 50 fathoms.
4. The infra-median zone, from 50 to about 100 fathoms.
5. The abyssal zone, from 100 fathoms to the greatest depth to which life could continue to exist.*

He likewise arranged marine life into nine homoiozoic belts (or belts of similar life), surrounding the globe, and also bounded by isothermal lines, one central or equatorial, and four on each side of it, which he called circum-central, neutral, circum-polar, and polar. Each of these belts, however, had its vertical zones as above, and did not merely correspond with one of them, like the botanical regions and zones.†

There is, indeed, a difference even in the distribution of temperature in the two oceans of air and water which surround the earth, arising partly from the difference in their physical constitution, and partly from their limitation in space. The ocean of air which surrounds the earth is uninterrupted except for very slight spaces near its lower surface, where there happens to be great irregularity in the vertical or relief form of the land on which it rests. The loftiest mountains or table-lands penetrate but a short distance up into the atmosphere. The ocean of water, however, not only rests on an irregular base, but is

* His researches led him to regard a depth of 300 fathoms as the probable zero of animal life, and that the deeper parts of the sea were therefore without life. More recent explorations, however, have brought to light an abundant fauna in the Atlantic at greater depths, and even living star-fish at 1000 fathoms. See Carpenter, *Proc. Roy. Soc.*, vol. xviii.; Wallich's *Atlantic Sea-Bed.*

† Johnston's *Physical Atlas*, 2d edition.

wholly included within a very irregular bed, its free circulation being continually impeded and deflected by large parts of that bed rising completely above it, and forming dry land. Even if we supposed, however, the sea to form as regular an envelope to the earth as the air does, there would nevertheless be a difference in the distribution of their temperatures. We may regard the distribution of mean temperature in the air, under the figure of shells or regularly-arched strata, superimposed one over the other, the hottest surrounding the earth about the equator,* the next spreading over that, and the next over that, and so on, each shell having a less mean temperature than the one underneath it. In Fig. 147 let C be the centre of the earth, and

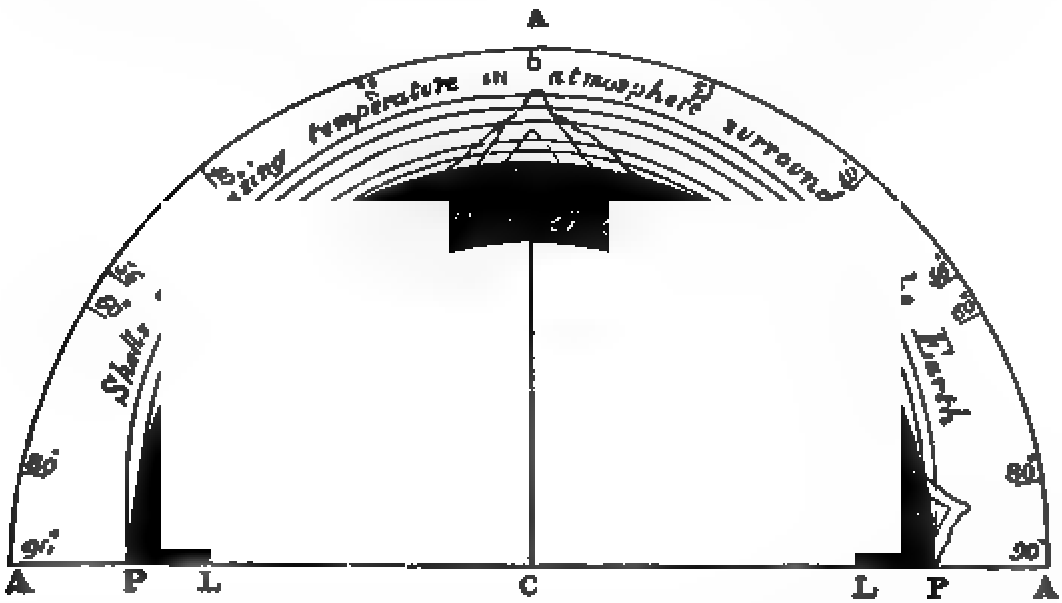

Fig. 147.

the blank semicircular space over L C L represent a section of half the solid part of the globe. Let the line C E be in the direction of the equator, and the line P L C L P be the polar axis of the earth, P P being the poles, and let the semicircle P E P represent the surface of the supposed uniform ocean of water, the depth of which, P L, is enormously exaggerated. Let the semicircle A A A represent the extreme limits of the atmosphere, quite as much exaggerated in height as the sea is in depth. Then the arched lines over P E P will represent sections of the supposed shells of decreasing temperature in the atmosphere, the hottest being the lowest just over E. The lofty mountain over E will penetrate all these shells, its summit being just in that stratum of cold which in its gradual descent reaches the sea-level about the poles.

About the equatorial regions of the earth, or in the neighbourhood of E, the decrease of temperature as we descend into the sea will take

* The equator of heat, i.e. the circumference of greatest mean temperature, does not exactly coincide with the true equator of the earth.

place in the same way as it does in ascending into the air. There will, however, be a limit to this decrease in the sea, unlike anything that we know of in the air. Taking the maximum temperature of the water at the level of the sea about the equator as 84° Fahrenheit, there will be inverted shells or saucers of cooler and cooler water beneath that till we come down to a minimum temperature of 27·2° Fahr. This is the temperature of the maximum density of sea-water, and therefore all the water below that depth must be of that same temperature, for if any particle of water below were made either hotter or colder, it would become lighter, and therefore float up to this level. But keeping in mind the figure of saucers or shells of water, it will be apparent that this frigid stratum will somewhere rise up to the upper surface of the sea, or *sea-level.* This will take place in arctic and antarctic latitudes, the water towards each pole becoming colder and colder, until it is eventually converted into ice.

The recent researches of the "Porcupine" expedition, under Drs. Carpenter and Wyville Thomson, and Mr. Gwyn Jeffreys, have shown that, while in the North Atlantic the surface temperature in autumn is pretty uniformly 52°, there exist below, even at corresponding depths, and in closely adjacent regions, two very distinct submarine climates, each with a characteristic and peculiar fauna. In one tract, called by these authors the cold area, the minimum temperature was 29·6°, and the animal forms were essentially of a boreal type; while, in close proximity, lay a warm area, where the temperature ranged from 42° to 48°, with a correspondingly temperate form of animal life. Dr. Carpenter infers that there must be a current of cold and heavy water flowing south from the pole, while another and warmer body of water is flowing northward from lower latitudes.*

As the earth rotates on its axis, the atmosphere and the ocean of course move with it. From the nature of circular motion it is clear that the more distant from the axis of the rotating body any point may be, the greater will be the circle it describes during each rotation. A point on the equator, then, will describe a larger circle during the twenty-four hours than a point on the latitude of 20°, 40°, 60°, or 80°. If a man travelled round the globe on the equator, he would make a journey of nearly 25,000 miles; if he could travel round it along latitude 80°, his journey would be little more than 4300 miles. It follows that if any body of air or water be moved vertically upwards or downwards, or travel directly towards the equator or the poles (*i.e.* northwards or southwards), it will have not only that absolute motion, but a relative motion eastwards or westwards consequent on the eastward movement of rotation of the part it arrives at being faster or slower than that of the part it left.

* *Proc. Roy. Soc.* xviii. and xix.; and *Proc. Roy. Inst.* Feb. 11, 1870.

Where the sun is vertical it exerts a greater effect on the portion of air directly beneath it, than on other portions. The air thus heated expands or becomes lighter and floats upwards. Similarly, the water of the sea is made warmer, and therefore lighter, beneath the vertical sun, and a greater portion is removed thence by evaporation from its surface. Air and water, therefore, are both sucked up by the sun to a greater extent where it is vertical than elsewhere. This vertical transference of air and water produces a direct north and south motion in the parts just outside the space sucked up, as they must rush in, in order to supply the place of that which is being removed; and these vertical, and direct north or south movements are partly turned aside in consequence of the rotation of the earth. Thus are produced those currents in the air which are called the trade winds, and the counter westerly winds outside the tropics. And thus, too, partly by changes of temperature, but almost wholly by this influence of the winds, currents are set in motion in the ocean, which are only not so regular as the trade winds in consequence of the interruptions in the circulation of the water arising from the interposition of land.*

As the sun is never vertical over the same spot two days in succession, except just at the solstices, but travels backwards and forwards over the central belt of the earth's surface, in consequence of the axis of the earth being inclined to its orbit, it follows that the place where these motions are generated is similarly movable, and oscillates during the year, now on one side and now on the other of the equator.

The irregular distribution of land and water likewise affects the position of the original moving impulse, in consequence of the difference in the heating power of the sun's rays on a land surface and a water surface, and the difference in the respective powers of radiation possessed by these two surfaces. This cause goes to the extent, in some localities, of setting up local centres of motion in the air, which shift their place according to season, or the place where the sun happens to be vertical, thus producing monsoons, or local periodical winds, instead of trade winds. The variations in altitude of different parts of the land produce still farther modifications in the air currents.

The complicated machinery thus set in motion over the central regions of the earth causes motion throughout the whole extent of the two oceans of air and water which surround the earth. A regular system of circulation is set up both in the atmosphere and the sea, its regularity being continually interrupted and disturbed by the irregular outline of the land and sea surface, and the irregularities in the *relief-forms* of the land, and to some extent in those of the bed of the ocean.

It thus happens that the climate of any part of the earth's surface, either terrestrial or marine, depending primarily on its latitude and its

* See some recent papers by Mr. Croll on Ocean Currents, in *Phil. Mag.* for 1870.

altitude or depth, is greatly modified by its position with respect to the hot or cold currents of air and water, and also by its proximity or otherwise to neighbouring great irregularities of surface, and the aspect of these irregularities. The important element of temperature has been graphically represented by means of what are called *isothermal lines*, pointing out the mean temperature of different places, either for the whole year or for the summer and winter months of the extra-tropical regions. The latter are often more important than the former, since it is obvious that two places may have the same mean annual temperature, and yet possess very different climates. One place, for instance, might have a mean winter temperature of 50° and a summer one of 70°, while another might have a mean winter temperature of 35° and a summer one of 85°, and yet both have a mean annual temperature of 60°.

Different species of plants and animals are differently affected by climate, some being, by their constitution, adapted for only one peculiar kind of climate, and perishing if they are moved beyond it, while others, more hardy, will survive, and some even flourish almost equally well, through many different kinds of climate. Man, and his companion the dog, are the animals which withstand best almost any amount of change in this respect.

It is obvious that when speaking of the influence of climate on plants or animals, it is necessary to include food in the idea of climate, because if the mere temperature and other circumstances be ever so suitable, the necessary nourishment must also be provided. Minerals are the food of plants, together with water and air. Animals feed either on plants or on other animals. Before plants can exist, then, in any part of the earth, or could come into existence on the earth at all, air containing carbonic acid gas, and water containing dissolved mineral matter, must have existed. In like manner, before plant-eating animals could exist, a sufficient stock of plants for their food must have been in existence, and likewise a sufficient stock of plant-eating animals, before the flesh-eating animals that were to be supported by feeding upon them. It must be recollected that this is true of marine and fresh-water, as well as of terrestrial beings.

Destruction, partial or entire, of Species of Plants and Animals.—The fact of the adaptation of species of plants and animals to peculiar climates (including food in the idea of climate), involves the necessity of the destruction of species as a consequence of an alteration in climates. If from any physical changes, such as those which are taking place continually in some locality or other, sea be converted into land, or land into sea, deep water into shallow, high land into low, or the reverse, such changes must involve the destruction of many of the species inhabiting the areas so changed, or of all of them, according to the amount

of change. Some of those species may have been limited to the areas thus affected: if so their destruction will be complete, unless they shift their habitation during the progress of the change, and establish themselves in new areas. Both total extinction and local extinction may thus be caused, the latter being the result either of the partial destruction of an inhabited area, or the result of migration from an area totally destroyed.

Another source of destruction is the removal by physical change of a barrier that once existed between the areas of two species, of which one is more powerful than the other, and destructive to it when both are inhabitants of the same area. One plant may thus outgrow and overwhelm another, or a plant-eating animal may usurp the food of another plant-eating animal, or a flesh-eating species may prey upon and directly destroy another species of animal, or indirectly destroy it by usurping its food.*

Add to these causes the effects of blights and murrains, or epidemic diseases among plants and animals, and we have enumerated all the most obvious causes of the extinction of species.

It seems to follow from these premises, that if physical causes of change were left to act for an indefinite time upon the life of the globe without any renovation of that life by the introduction of new species, the whole world would ultimately be tenanted only by the comparatively few more hardy species which could survive all these changes; and it seems also to follow, that wherever two parts of the globe, however distant, had similar climates, we should find in them the same species of animals and plants.

The Origin of Species.—Naturalists have long experienced the utmost difficulty in determining the limits of species. This difficulty has been felt both as to plants and animals, with respect to living as well as fossil forms. One man has made several distinct species out of various forms which another has considered as mere varieties of one species. The only satisfactory test of the distinctness of species that has ever been agreed upon is that derived from the power of a species to reproduce its like. The individuals or pairs of a species are fertile, and produce their like, while it is impossible to procure a cross between two different species unless they are very closely allied, and then the progeny is called a mule or hybrid, and remains barren. It results from this principle, that the whole of the individuals of a species are the descendants of a common parentage. Doubt, however, has been cast upon this test with respect to some plants, and even to some

* One species seems sometimes to be animated by pure hostility to another, as in the case of the black and brown rats. The old English or black rat was said at one time to be universal in our islands; whether it ever spread beyond them I am not aware, but the rat which is now common, and called the brown or Norwegian rat, is said to have been introduced, and to have almost entirely extirpated the other.

animals. Many naturalists, for instance, believe that some of our domestic animals, as the dog, are the commingled descendants of two or three species originally distinct. In this view, a hybrid or mule, the result of the crossing of distinct species of plants or animals, is merely an exaggeration of a mongrel or cross between distinct breeds or varieties. Still there seems to remain an essential distinction between a species and a mere breed or variety in this respect, and not only a distinction, but a contrast, for while the offspring of distinct species are usually not only sterile but degenerate in strength and appearance, the "crossing of breeds" almost invariably improves the descendants, both in fertility and every other respect.

Mr. Darwin, in his *Origin of Species*—a work which marks a great epoch in the history of science—accounts for the origin of species by a doctrine which he terms that of natural selection. I will endeavour to give a brief account of his hypothesis.

Species of plants and animals have a natural tendency to produce "breeds," "races," or "varieties," under the continual influence of external modifying causes, or all those surrounding circumstances which we may include under the term of "climate." If any number of individuals be placed in a favourable "climate" (including food and everything relating to their wellbeing under the term "climate"), then those individuals will gradually become an improved breed. If the "climate" be unfavourable, the breed will degenerate. If, again, in any region in which the same climate prevails throughout, individuals of a species of plant or animal should be produced by any physiological or other accident, differing in any important way from the other individuals of the species, and that difference (whether it might to us appear an improvement or the reverse) should be of any advantage to the individual possessing it, it would naturally be used and strengthened by use and exercise, and transmitted to the progeny of those individuals.

In this way a process would be set up naturally, similar to that which breeders of plants or animals follow designedly. A breeder selects the individuals which happen to possess the qualities he desires, and breeds from them, taking care to surround them during the process with the kind of "climate" favourable to the success of the process. The differences artificially produced in breeds are very striking; such as the difference between the Shetland pony, the Flemish cart-horse, and the English racer; that between different breeds of sheep and oxen; the difference between the varieties of fruits and vegetables; the different breeds of domestic poultry; the different pigeons of pigeon-fanciers; and the vast variety of dogs, though Mr. Darwin believes that the latter is to some extent to be accounted for perhaps by the commingling of two or three allied species.

His hypothesis is that these varieties which are so numerous, and some of which remain so unchanged, may, if the surrounding circumstances conducive to them remain for a great length of time unaltered, result in the production of new species. He looks upon the difference between a permanent variety and a species as one which has every degree of gradation, and finally vanishes.

The obvious objection to this hypothesis is that no one has yet succeeded in producing a new species, that is, a breed or variety of animal or plant which is incapable of propagating its kind with other breeds or varieties of the species from which it was itself originally derived. This objection, however, is merely saying that Mr. Darwin's hypothesis has not yet been converted into an undoubted

theory by proof tantamount to absolute demonstration. His hypothesis may be true, even if man is incapable of doing the work of Nature, from want either of the requisite time, or of all the means which Nature uses. It is, moreover, one which the professed biologist alone is competent to discuss. To a question in pure physiology, the answer of the physiologist only is of any value as an authoritative opinion.

Sporadic Origin of Species.—A species of plant or animal apparently consists of the descendants of some one individual, or pair of individuals, which originated on some spot of the earth's surface. These spots were called by Professor Edward Forbes specific centres, because, as the descendants multiplied, they spread themselves in all directions round them as far as time and climate (that is, all the surrounding circumstances) would allow. These originating spots or centres seem to have been scattered broadcast over the world. Every large area of the world has species of animals and plants peculiar to it, and some very small areas, such as little islands remote from any other land, or detached lakes and seas, have in like manner been found to be inhabited by species which did not exist anywhere else. We cannot escape the conclusion, that either direct creation, or the action of some principle of variation and multiplication of forms, has been in frequent or continuous operation in all parts of the globe, both on land and in the water.

Schouw divided the globe into twenty-five botanical regions, in each of which at least one half of the known species, a quarter of the genera, and some individual families, were peculiar to that region, and found nowhere else. These regions are scattered variously over the globe, but they admit, as shown by Meyen, of an arrangement into zones, each zone surrounding the earth, and including regions in which, although the plants are distinct, yet they are more like and more nearly allied to each other than those of other zones. Not only are the regions of plants in each of these zones similar to each other, but there is another kind of similarity in those of corresponding zones in the opposite hemispheres, so that the plants may be said to be, although entirely distinct, representative of each other. The evergreen forest trees, for instance, of the northern warmer temperate zone, are represented by other evergreen forest trees in the south warmer temperate zone, each latitudinal zone still having its distinct vertical regions of plants, as before described.

Some particular species of plants are confined to very small areas. Small islands, for instance, such as Madeira and Teneriffe, have species of plants which are found nowhere else. In the Canary Islands, generally, out of 533 species of phænogamous plants, 310 are peculiar to them. On St. Helena, out of thirty native species of phænogamous plants, only *one or two* exist in any other part of the globe. In the little archipelago of the Galapagos Islands, there are a hundred species

of flowering plants found only in those islands, some only on some of the islands and not on the others.*

The same rules hold good in the animal kingdom. The Canaries and Galapagos are marked by the large admixture of indigenous species in their fauna.† Dr. Sclater divided the distribution of birds over the globe into six regions,‡ which Mr. A. R. Wallace has proposed to adopt as good for the whole animal kingdom.§ These regions are—1st. *Neotropical*—South America, Mexico, and West Indies. 2d. *Nearctic*—The remainder of America. 3d. *Palæarctic*—Europe, North Asia to Japan, Africa north of the Desert. 4th. *Ethiopian*—The rest of Africa and Madagascar. 5th. *Indian*—South Asia and western half of Malay archipelago. 6th. *Australian*—Eastern half of Malay archipelago, Australia, and most of the Pacific Islands. Mr. Wallace remarks that the mammalia, reptiles, land-shells, and to a great extent the insects, agree with the birds in this distribution. The greatest discrepancies occur in groups which have at once great capacities for diffusion and little adaptability to change of condition.

The boundaries of these various provinces or regions are sometimes very well marked. This is especially the case wherever any strong natural feature occurs, such as the separation of two land provinces by a chain of inaccessible mountains, or by a narrow and deep sea, or that of two marine provinces by a narrow neck of land, or the meeting of a warm and cold current of water. At other times adjacent provinces may be more or less blended into each other, so that it is difficult to say where one ends and the other begins.

M. Barrande ‖ has some very instructive remarks on the close approximation of widely distinct marine provinces. Wherever two spaces of sea are separated by a narrow neck of land, uniting countries which stretch far and without interruption through different climates, we may have totally different species within a few miles of each other. This happens at present in the instances of the Isthmus of Suez and Isthmus of Darien. In the first case, according to the best authorities, there are no species of fish or crustacea common to the Red Sea and the Mediterranean, with the exception of a few cosmopolitan species; neither are there any species of molluscs common to the two seas, with a few doubtful exceptions; while, with regard to the zoophytes, this is true without any exception at all. In the second case, on the authority of M. Alcide D'Orbigny, there are 110 genera of mollusca on the two coasts of South America, of which fifty-five are common to the Pacific and Atlantic Oceans; thirty-four peculiar to the Pacific, and twenty-

* Humboldt and Darwin, as quoted by Lyell. *Principles*, 9th edit., chap. xxxviii.

† See Lyell, *op. cit.*, 10th edit., vol. ii. chap. xli.

‡ *Trans. Linn. Soc.* 1857. § *Nat. Hist. Review*, 1864.

‖ In his *Parallèle entre les depôts Siluriens de Bohême et de Scandinavie.*

one peculiar to the Atlantic. There is, therefore, a generic correspondence to the extent of one half; that half being probably the most important, and containing the greatest number both of species and individuals. But these 110 genera contain 628 species, and of these *one only* is to be found common to the Atlantic and Pacific Oceans.

Examples of the Geographical Limitation of Animals as proving their Sporadic Origin.—In order not to leave the reader with mere dry abstract generalisations, it may be advisable to mention a few of the best known and most marked examples of the limitation of certain species and genera of animals.

α, *Fish.*—The sea-fish vary greatly in different parts of the world. The cod, the turbot, and the sole, are peculiar to the Arctic seas and the adjacent parts of the Atlantic. The salmon accompanies them, but runs down the western coast of North America as far as the Columbia River, while in Europe, it is never found, I believe, in any river running into the Mediterranean or Black Sea. The tunny and other Mediterranean fish are in like manner unknown in the Atlantic. The fresh-water fish are equally limited in some parts of the world.

β, *Birds.*—Perhaps the most striking facts of limitation of species, however, are those occurring among birds; whose powers of easy and rapid locomotion seem to place the whole world at their disposal.

Some birds do range over very large parts of the earth, but others are limited to the smallest territories. The red grouse of our own islands is not known to exist in any other portion of the earth. The nightingale, which visits the south-east of England during the summer, and abounds then in Cambridgeshire, and extends even to Northampton, stops at a certain line, running thence down into Somersetshire, and is never heard to the north-west of that line.

Perhaps there is no more striking instance of the restriction of species to narrow limits than that observed by Mr. Darwin in the Galapagos.* Here we have a small cluster of islands all volcanic, and all of the same character, and all nearly under the equator, and therefore enjoying the same climate, and yet not only have they a fauna and flora distinct from that of the rest of the world, but different species are found in the different islands, making the group into a little world of its own, a satellite, as it were, of the great American continent. The animals and plants bear the American stamp, resembling those of America more than those of any other part of the world; they are, however, specifically and even generically distinct. The islands contain no indigenous mammal except one small mouse, but numerous reptiles, snakes, lizards, and tortoises, some of the lizards being marine, and the only living species of their class that inhabit the sea, and the large land-tortoises being also of very peculiar forms. Among twenty-six species of land-birds, only one is known elsewhere, and some even of these were absolutely confined to particular islands, although some of those islands were within sight of each other.†

Returning for another instance to Australia, we find that there are peculiar species of parroquet and other birds in Victoria, South Australia, and Swan River, differing from each other, and from those of New South Wales, while many of the latter range along the whole stretch of the eastern coast, from 40° S. lat. to within 10° or 12° of the equator. The same species in this case seem to cling to one range of high land, even though stretching through different climates, while they do not cross the intervening plains on to other mountain ranges, which yet are in the same latitudes and enjoy the same climates as the eastern coast range.

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* See his *Naturalist's Journal.*

† Darwin, *op. cit.*

The Dodo, which inhabited the Mauritius, and was exterminated by the Dutch, and the large and beautiful Norfolk Island and Philip Island parrots, each confined to its little spot of earth, and exterminated by the English convicts, are conspicuous instances of the restriction of large birds to small spaces, and their consequent extinction on the introduction of the hostile species—man. The humming-birds afford excellent examples both of great range in some species, and of close restriction in others. Humming-birds are peculiar to the American continent, they are found over the whole of it from Cape Horn to Russian America. A small blazing-red species (called *Salasporus rufus*) ranges from Mexico to Sitka. On the other hand, the one called *Oreotrochilus Chimborazo* is only found on the mountain from which it takes its name, and only between the altitudes of 12,000 feet and 15,000 feet above the sea; another called *Oreotrochilus Pichincha* is only found between the altitudes of 10,000 and 14,000 feet upon Pichinca. *Ereocnemus Derbianus* has never been found except in the crater of the volcano of Puraci.* The ostriches and their allies are equally remarkable as exhibiting the organisation of different species of birds, all unable to fly, in so many different parts of the earth. The ostrich proper (*Struthio camelus*) inhabits Africa and Arabia. In South America there are two species of ostrich, one (*Rhea Americana*) inhabiting the eastern plains north of the Rio Negro, the other (*Rhea Darwinii*) the plains of Patagonia. In Australia we have the Emeu (*Dromaius Novæ-Hollandiæ*); in New Guinea and the neighbouring islands the Cassowary (*Casuarius galeatus*), and another species from New Britain; and in New Zealand the *Apteryx* and the recently exterminated *Dinornis*, of which Owen enumerates twelve species. There was another bird also (called *Æpiornis*) in Madagascar, now known chiefly by its eggs, one of which would have held the contents of 148 eggs of the common fowl.†

It is impossible, as Owen remarks, to suppose that all these different species of birds which can neither fly nor swim, nor endure severe climates, could have sprung from one common Asiatic centre, according to the generally received hypothesis of the origin of species. It is also equally difficult to understand why that strange anomaly, a bird unable to fly, should have been developed by any physiological law, such as Darwin's doctrine of variation, in so many independent localities, though that objection might perhaps be met by the supposition of the gradual breaking up and separation of once continuous land, so that a non-flying bird once produced, might afterwards vary into many different kinds of non-flying birds in the different separated areas.

As a contrast to birds which cannot fly at all, we may instance many oceanic birds who seem to pass their lives upon the wing, and yet never or very rarely overstep certain limits. In the South Indian Ocean, between the Cape of Good Hope and Australia, the sea during the winter months of the southern hemisphere is alive with birds south of latitude 31° or 32°, while to the north of that line none are seen except an occasional tropic or frigate bird. Towards the south flocks of albatrosses and cape-pigeons seem as if always accompanying the vessel in its course, the cape-pigeons ever busy about the ship, while the great albatross (*Diomedea exulans*), and the still more numerous dusky species (*D. fuliginosa*) sweep in steady curves between the ship and the horizon, now sailing close by the rigging and eyeing the persons standing on the poop, and then gliding out of sight ahead, as if the vessel were at anchor. If, however, the ship turn towards the north and pass the limit mentioned above, all these hosts of birds disappear at once, nor are they ever seen again till the navigator return to the south, when he finds fresh flocks as if awaiting his arrival.

γ, *Mammalia.*—We find similar restrictions as to the areas inhabited by species or groups of species among the highest class of animals—namely, the

* From information communicated by Mr. Gould.

† Owen, Address to the British Association, Leeds Meeting.

mammalia. In the Arctic regions, indeed, many animals, such as the musk-ox, the polar-bear, the right northern whale, and others, both terrestrial and marine, are common to the whole circle. But as we travel south, and the lands and seas begin to diverge from each other, the animals, even in corresponding latitudes and similar climates, soon become diverse. The black and grizzly bears are American only, the brown bear is an inhabitant of the Old World alone. Still farther south, the puma and jaguar of America represent, but are very different from, the lion and the leopard of the Old World. The camels and dromedaries of the Old World are similarly represented by the llamas and guanacoes of the New; and each great division of the globe is inhabited by many different species of deer and other corresponding animals. The monkeys may be divided into three groups—the Catarhini, belonging to the Old World, the Platyrhini, to the New, and the Strepsirhini, most of which belong to Madagascar.

There are, however, many groups of animals wholly confined to one of the great divisions of land. No true pig (*Sus*) was a native of America, the peccaries (*Dicotyles*) are American only. There are now no representatives in the American continent of the elephants, and there appear never to have been any of the rhinoceroses, hippopotami, or giraffes of the Old World; while the sloths (*Bradypus*), the anteaters (*Myrmecophagus*), and the armadillos (*Dasypus*), are not met with out of America. There is indeed a pangolin (*Manis*) in Africa, and another in Asia, and an *Orycteropus* in Africa, otherwise the whole order of Edentata would be entirely American. There is, however, a still closer restriction among the species of each of these animals. One species of elephant is peculiar to Africa, and another to India. There are three species of double-horned rhinoceroses in South Africa, and one in the island of Sumatra, Java having another with only one horn. There are different species of sloths, anteaters, and armadillos in different regions of South America.

The marsupial animals are now confined to Australasia, with the exception of one genus, the didelphys or true opossum, which is American only, some of its species being restricted to very narrow limits. In Australasia the marsupials of New Guinea are entirely and some of them widely distinct from those of Australia proper, and in Australia itself the kangaroos, wallibis, and phalangers, are different in different parts of the country. Mr. Gilbert, who was collecting for Mr. Gould, and unfortunately lost his life in Dr. Leichardt's first expedition, informed me, when I met him at Swan River, that with the exception of the *Echidna*, or so-called Australian porcupine, he had not been able to find a single animal or a single bird among all those he had collected in Western Australia, that was specifically the same as any in New South Wales. The lesser island of Tasmania has the two largest and most powerful carnivorous marsupials absolutely peculiar to it, those, namely, which are called the Native Tiger (*Thylacinus cynocephalus*), and the Devil (*Sarcophilus* (*Dasyurus*) *ursinus*). That strange animal, the duck-billed Platypus, or *Ornithorhynchus paradoxus*, appears to be confined entirely to the south-eastern corner of Australia.*

Generic Centres and Districts.—That any one species should be confined within certain limits round its point of origin seems natural or inevitable as the direct result of the action of climate, or the physical limitation of the land or water area in which it came into existence. It is, however, very worthy of notice, that those groups of allied species, which we call genera, are equally circumscribed. Why should different species of opossum (*Didelphys*) have originated in America, side by side

* See Owen's Presidential Address, previously cited; Johnston's *Physical Atlas*, etc. etc. etc.

with each other, and nowhere else? Why should different species of kangaroo (*Macropus*) and other marsupial genera have originated in Australasia, and in no other part of the world?

If the limits of a species be the natural result of the descent of the individuals composing it from a common mother, does not the limitation of a genus point equally to descent from a common species? The same question might be asked as to the limitation of the different genera comprising a family or order, making allowance for the obvious condition that the larger the group of species (genus, family, or order), the larger is the area likely to be occupied by it, and its limitation will become therefore less and less obvious. The fact, however, that genera (of whatever extent) are geographically limited, is one that is provable by many examples both among plants and animals. Edward Forbes insisted on it strongly, and pointed out that genera had their *centres* where their *species* were most numerous and flourishing, in the same way that *species* had their centres where the *individuals* flourished best, and that, receding from those centres, both vertically and laterally, individuals in the one case, and species in the other, gradually faded away, till at certain limits they ceased to exist.

These facts are highly suggestive when we come to speculate on the origin of the various forms of life upon the globe. They seem, in connection with the geological history of some species and genera, to have originated in Darwin's mind those speculations of which the first-fruits were given in his *Origin of Species.*

Breaking up of Generic and Specific Areas by Geological Changes. —Certain facts in distribution at the present day which seem to militate against the truth of the limitation of genera (and perhaps of species also), are easily explained when we learn their geological history. Edward Forbes, for instance, pointed out that the genus *Mitra* has at the present day its centre in his central homoiozoic belt, its area extending thence through the two circumcentral and into the south neutral belt, but that one outlying species,* *Mitra Greenlandica*, was found in the north polar belt. This detached species, which seemed to form so striking an exception to the doctrine of continuous generic areas, is, however, known to have once formed part of the great generic area of *Mitra*, inasmuch as *Mitræ* of other species formerly existed in the intermediate space. The extinction of these species of *Mitra* has broken up the once continuous area; and it is probable that the many physical changes which have taken place, and the mutations between land and sea, and height and depth of either, have in many instances broken up generic and specific areas, and either contributed to their dispersion, or perhaps in some cases aided in restricting them within still narrower limits.

* If it be a *Mitra*, which is, I believe, at least doubtful.

A little consideration will show that if the individuals of a species, or the species of a genus, be rare, and their limits narrow, it may be either in consequence of their being new, only just beginning to make their way in the world, or because they are old and dying out. If they be found in two or three localities widely apart, the latter is almost certainly the true state of the case. There is a genus of fresh-water fish called *Coregonus*, the porran of Cumberland, the pollan of Lough Neagh, the Gwynniad (or white fish) of Bala Lake, the white fish (or fresh-water herring) of the North American lakes, other species being found in the Siberian rivers. Some of the North American and Siberian species are very abundant in their several localities,* but those of the British lakes are rare fish, only occurring in the detached lakes mentioned above, and only to be seen at particular seasons even in them. They are, doubtless, remnants of those which, when the arctic climates of North Siberia and America extended over the British islands and the whole northern area of the world, were equally abundant over the whole of that area, and are now approaching extinction in different isolated localities of the area where arctic climates no longer prevail.

The geological bearings of the facts of the geographical distribution of organic beings at the present time now become apparent, and three other instances may be briefly given.

It is said that the existing fauna and flora of North America have remarkable generic and ordinal analogies with those which prevailed in Europe during a recent tertiary age. There is perhaps a closer relation between those recently extinct European genera of animals and plants and the existing North American ones, than there is between the latter and the present European genera. It is possible, therefore, that the present European fauna and flora may be of more recent date than those of North America; that genera and species, once common to the two continents, have remained less changed in North America than in Europe, where they have become extinct by some of the actions previously alluded to, and have been replaced by other forms. The climate of North America has probably been less altered since the glacial period than that of Europe has.†

Mr. Bates ‡ describes the arboreal character of the mammals, birds, reptiles, and insects of those regions of South America, compared with their analogues in other parts of the world, and attributes it to the gradual adaptation of the species to the necessities of life in the vast forests of those regions.

The animals and plants of Australia are very peculiar, and many of them such as are found nowhere else living in the world. Some of the marine shells and some of the land animals and plants more resemble those found fossil in rocks deposited during an early geological period (the Oolitic) in our part of the world, than they do any other ordinal or generic types. It is perhaps possible, therefore, that the fauna and flora of Australia are, as it were, a remnant of that which, during the Oolitic period, was common to the whole globe, but which has everywhere else been superseded by the introduction of new generic and ordinal forms.

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* See Richardson's *Polar Regions*.

† See on this subject the papers of Professor Heer, and the discussion of it by Sir Charles Lyell in his *Elements of Geology*, 6th edit. chap. xv.

‡ In his interesting *Voyage up the Amazons*.

CHAPTER XXVIII.

THE LAWS AND GENERALISATIONS OF PALÆONTOLOGY.

The Kinds of Animals and Plants most likely to occur Fossil.— The rocks in which organic remains are found are aqueous rocks, principally marine. We should, therefore, naturally expect the enclosed fossils to be the remains of aquatic, principally marine beings. In the vegetable kingdom, at the present day, the vast majority of the species are terrestrial, while in the animal kingdom there is an almost equal majority of aquatic species. Among the Vertebrata, for instance, we have two orders of mammalia entirely aquatic, a large part of the reptiles and amphibia, and the whole of the fish. In the sub-kingdom Annulosa, the insects, indeed, like the birds among the Vertebrata, are chiefly terrestrial or aerial; but the Crustacea are chiefly, and the Echinodermata entirely, aquatic. The exceptions to the aquatic character of the rest of the whole animal kingdom, including the mollusca and the other sub-kingdoms, are very few and comparatively unimportant, the pulmonata, or land-snails, being the principal one.

This at once gives us a reason for the fact of the remains of animals being more numerous than those of plants, and of aquatic animals than those living on land. Even where they occur in equal abundance, animal remains are more important than vegetable, inasmuch as it is more easy to arrive at definite conclusions as to the nature and the habits of the once living beings from the examination of a fragment of an animal than from that of a plant. A single scale, or tooth, or fragment of bone or shell, will often reveal to the comparative anatomist the whole history of an animal which he certainly never saw, and of which, perhaps, the only known traces may be that solitary fragment. The botanist is not in equally favourable circumstances for determining the history of a fossil plant, since a piece of a stem or a leaf will rarely do more than enable him to determine to which great division of the vegetable kingdom the living plant belonged; while the parts, such as the flower, on which he mainly depends for more exact determination, are scarcely ever preserved in a fossil state.

It is to the terrestrial animals, as most important to us economically, and most frequently before our eyes, that we are naturally accustomed to look as our fellow-inhabitants of the globe, but in reality, if we

except the terrestrial mammalia, the birds and the insects, almost all the infinite variety and abundance of other animals live in the water. We should therefore naturally expect to find, as we do, portions of all the other kinds of the animal kingdom in great plenty, while remains of mammalia, of insects, and of birds, must be comparatively rare.

It is necessary to take these considerations strictly into account before we found any reasoning upon the negative evidence of the absence of terrestrial animals or plants in a fossil state. Very important conclusions are doubtless to be drawn from the study of the terrestrial kinds when they do occur fossil; but even then their practical value to the geologist is often small, on account of their rarity. Many of the extinct species and genera of mammalia, for instance, are founded upon the occurrence of single fragmentary specimens, or of not more than two or three specimens; fossil fish are more numerous, but the testaceous (or shell-bearing) molluscs, the crustacea, the echinodermata, and the corals, occur by hundreds and thousands, mountainous masses of rock being in some cases made up of them. We might accordingly take any one of these last mentioned, and compare the different assemblages of them found fossil in different formations, with the expectation of arriving at some definite conclusion as to their history. Of all fossils, however, the mollusca afford to the palæontologist the most complete and unbroken scale of comparison, on account of their number, their variety, and the comparative completeness of the preservation of their fossil parts, and the consequent facility of determining their nature and habits.

The Modes of Occurrence of Fossils.—Breaks in Succession.—Organic remains may be either included in the aqueous rocks on the very spot where they lived, or close to it, or may have been drifted by the water to some distant spot after death, or swept into the water from the land. Any remains floating for some distance in water, and slowly sinking to the bottom of it, or drifted for any distance along the bottom, will give us no information as to the habits or "station" of the species when living. We may get fragments of land plants or animals included in beds which were deposited in deep sea at a distance from shore, or fragments of animals which lived in clear water deposited in mud or silt, or of animals which lived in sand or mud enclosed in limestone formed in clear water. These, however, are the exceptions rather than the rule, and in the majority of instances the animals found as fossils lived on, or close to, the spot where they were buried, so that in pure limestone we get the remains of animals that lived in clear water, while in sandstones and clays we get the shells and other animals that preferred to live in or on sandy and muddy bottoms. Hence, when we examine any group of aqueous rocks, made up partly of calcareous, and partly of arenaceous and argillaceous rocks, we may

expect to find a difference in the fossils according to the difference in the nature of the rock. Fossils are in general much more numerous in limestone than in any other kinds of rock, because limestone is chiefly derived from the remains of animals; but certain kinds of fossils, even certain species of shells, are found mostly in sandstone, others mostly in mud or clay. Land-plants and other terrestrial productions are found much more frequently in arenaceous and argillaceous rocks, because these are more usually deposited near the land than calcareous rocks are.

These general statements must of course be taken as mere generalisations, admitting of many exceptions, and must not be construed into absolute rules rigorously governing particular cases. Allowing for exceptions arising both from the drifting of organic remains before they are buried, and from abnormal variations in the deposition of different kinds of rock-material, we shall find in each group of rocks limestone fossils, and sandstone or clay fossils. A series of groups of beds, then, will contain different fossils in different parts, according to variations in the nature of the rocks, as well as to changes in physical conditions during the lifetime of the fossils—changes which are sometimes distinctly indicated to us by unconformable breaks in the strata.

We may represent this law of the distribution of fossils by the following diagram:—

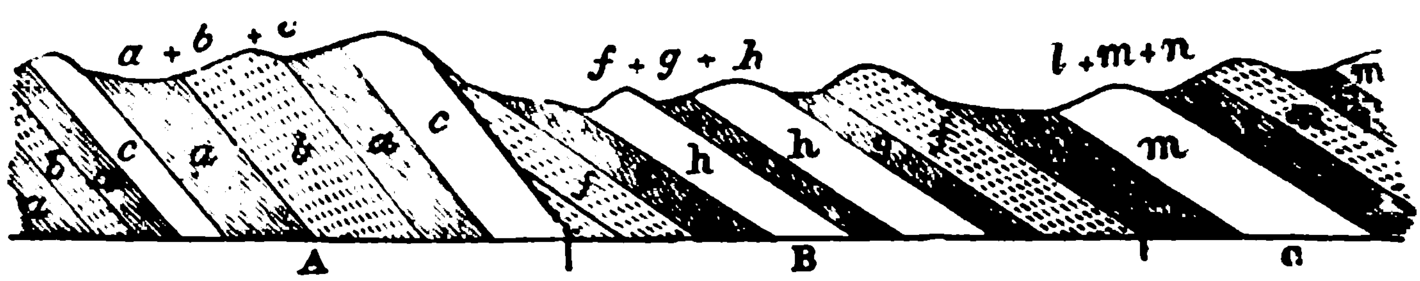

Fig. 148.

Let Fig. 148 represent a section through a great series of rocks made up of alternations of argillaceous rocks represented by lines, arenaceous rocks represented by dots, and calcareous rocks represented by the plain bands. Let the series be divisible into three groups, A B C: then in the lower group A we may find certain fossils peculiar to the argillaceous beds, let us call those fossils the *a* assemblage; certain others peculiar to the arenaceous beds, let us call those *b*; and others to the calcareous, which we may call *c*. Throughout this series of rocks these peculiar assemblages of fossils may recur wherever we get the peculiar kind of rock. The *a* fossils in the lowest set of clay beds will be replaced by the *b* fossils in the sandy beds above them, but the *a* fossils would recur when we examined the next superior set of clay beds. If over those we met with a set of limestone beds, we should find the *c* fossils in them; and so as we crossed the successive outcrops of the beds, and came to others similar in lithological character to those we

had left, we should find similar fossils recurring, the *a* fossils in the argillaceous beds, the *b* fossils in the arenaceous, and the *c* fossils in the calcareous. This change in the assemblages of fossils might take place equally, whether the change in the nature of the rocks took place laterally as they ranged across a country, or vertically as the beds succeeded each other in order of superposition. We should then include the whole assemblages $a + b + c$, when we spoke of the fossils that were peculiar to the whole group of rocks A. There might also very possibly be a certain mixture of fossils throughout, or certain species might range throughout, independent of those which were peculiar to the different kinds of rock.

When we passed beyond the limits of the group A into that of group B, we should then find an assemblage of fossils of altogether a different kind. Group B might equally be made up of sets of argillaceous, arenaceous, and calcareous rocks; and each of these sets might contain peculiar assemblages of fossils, which recurred in any part of the group whenever the peculiar kind of rock recurred. Moreover, there might be little or no difference between the clays and sandstones of group B and those of group A, and the limestones of each might be equally similar, so that no one could distinguish between the beds of group B and those of group A by any difference in the nature of the rocks. The fossils, however, might be so dissimilar as to leave the two groups not a single species in common; or the common species would at all events be a very small proportion of the whole. The limestones of B would have an assemblage of fossils we may call h, its clays one we may call g, and its sands one we may call f; and the total assemblage $f + g + h$, together perhaps with others common to the whole, would be the peculiar fossils of the group B. The reason of this great discrepancy between the fossils of the groups A and B is to be sought in the fact that these two groups are separated by an unconformability which points to changes of physical conditions, and to a long interval of time during which the fauna suffered corresponding change. This abrupt transition from one group of fossils to another in the same great series of rocks is called a *break in the succession* of organic remains.*

The group C might in like manner have its argillaceous fossils l, its calcareous or limestone fossils m, and its sandstone fossils n, each re-appearing in different parts of the group according as the kinds of rock recurred, the whole assemblage $l + m + n$ being the peculiar fossils of C. In this case there is no unconformability, and no record of any important physical changes between the deposition of B and C. Yet the mere fact that there is a break in the succession of the fossils between these two groups suffices to prove that such changes, though otherwise unrecorded,

* See Ramsay's Addresses to Geological Society.—*Quart. Journ. Geol. Soc.*, vols. xix. and xx.

must have taken place during a long lapse of time, to allow the species of B to disappear, and their places to be taken by those of C.

The student must not expect often to find formations containing such a frequent recurrence of different kinds of rock, all fossiliferous, as we have supposed in the diagram, and each assemblage, either of the smaller single groups, or of their triplicate unions, so neatly distinguished from each other as is here represented.* Sufficient examples, however, could be easily adduced to show the tendency of natural operations towards such a state of things, and that, if circumstances had allowed of the production of alternating groups of beds all containing the remains of the animals that lived during the periods, on the different kinds of sea-bottom, we should then have had a series answering to the one supposed above. This would have been the case, indeed, throughout the whole series of stratified rocks, if it had been possible for deposition of beds and entombment and preservation of organic remains to have been continuous. The deposition of the materials of rock, however, has been irregular and interrupted, the beds of each great formation having been formed at intervals, with long pauses of non-production between them. When we add to this the fact that the chances against the entombment and preservation of organic remains, especially in clays and sands, must always have been many, and that our series of fossils contains but a few scattered fragments of the vast series of forms of life which have inhabited the globe, we shall feel at once that we can glean from them, at least in the meanwhile, only faint sketches of the laws which have governed the distribution of these forms, and that we must not look for a perfection and completeness of evidence which the nature of the case renders impossible.

The Geographical Distribution of Species in past time.—When geologists first learnt that groups of rock-beds were very widely spread over large areas, and occurred in a certain order of superposition within these areas, and when they gave names to those groups derived from their lithological character, such as "the Chalk," "the Oolite," "the Mountain Limestone," "the New or Old Red Sandstone," they naturally were inclined to extend the boundaries of such groups of rock indefinitely, and to suppose that the very same kinds of rock would be found in the same order of superposition in all parts of the earth. Travellers did not hesitate to speak of the groups of rock which they found in new countries by these names, trusting simply to the nature of the rock for their identification. In like manner, when more notice was taken of the fossils contained in these "formations," and observers looked to them rather than to mineral characters for their identification of a formation, they were at first naturally inclined to conclude

* On the triplicate association of sandy, clayey, and calcareous rocks in the geological formations, see a paper by Mr. Hull on "Ternary Classification." *Quart. Journ. Science* for 1879.

that these fossils would be common to the same formation all over the earth. There is often a much closer resemblance in the organic remains found in distant parts of the same formation than there is in its lithological characters ; nevertheless there is in many cases a difference in the species which is due to the influence partly, perhaps, of difference in climate, but chiefly to the fact of the sporadic origin and consequent geographical limitation of species.

Even in the earliest periods of the earth's history which we know anything about, the species of the genera or orders which existed in those times were evidently limited to certain provinces, as species are now. Different species having come into existence at certain spots in different parts of the earth, the individuals of those species spread around their centres so far as "climate" (*i.e.*, all surrounding circumstances, including food), allowed of their diffusion.

As climate is so much modified by the distribution of land and sea, and of high and low land, shallow and deep sea, and the variation in the currents of air and water, it follows that since the places of land and sea have been continually changing, the climates of different parts of the earth must have been frequently modified ; and we know, from facts which will be hereafter described, that the climate of the whole earth has also varied. The position, the size, and the number of biological provinces, then, may have varied very greatly at different periods of the earth's history. There may have been formerly only a few large provinces like that of the Indo-Pacific ocean of the present day. This may especially have been the case if the climate of the earth generally were once more equable than it is now, with less cold in the polar regions, and possibly no higher temperature within the tropics than is felt in the equatorial islands of our own times. Under such circumstances it is most probable that in former times the cosmopolitan species, or those which ranged over the whole earth, may have been more numerous than they are now. Still, however the examples of the rule may have varied from time to time, it is very important to note that the law of the geographical limitation of species, both laterally and vertically, has always prevailed.

In examining, therefore, the distribution of fossils in different parts of the earth's crust, we must bear in mind that there are three causes of change in them :—

1. First of all, within the same biological province there may have been differences in the "stations," to use the naturalists' phrase ; that is, the place where the fossil was buried may have been at the time either sea or fresh water, deep or shallow water, near shore or far from it, having a muddy or a sandy bottom, or being a sea clear of sediment ; and the fossils entombed at these different stations of the province may have varied accordingly.

2. Secondly, we may pass from one "province" into another, the two provinces having been inhabited by different but contemporaneous groups of species.

3. Thirdly, there may have been a difference in "time," during which a general change had taken place in the species, those formerly existing having become extinct, and others having come into existence which had not previously appeared on the globe.

Difficulty in determining the Contemporaneity of Distant Formations.—It has been stated in the preceding chapter, that a change in the physical circumstances of a district may cause either a local or a total extinction of species, according to the rate and amount of the change. If the change operate slowly and gradually, the individuals of the species may have had time to travel with it, and to settle themselves in a new area, even as a consequence of the change. Moreover, if any species, originating in a certain spot, become subsequently cosmopolitan, or very widely spread, this diffusion may require a vast period of time, so that, even if the existence of the species be of equal length at different parts of the globe, the dates of its commencement and extinction may have been widely different in those parts. It may have even become extinct in its original centre before it reaches some of the more distant parts of the whole area occupied by it.

The fact of particular species, then, being common to the rocks of two distant localities, is by no means a proof of their being *exactly contemporaneous* in point of time. It may prove the very reverse of this.* Such strict contemporaneity in the rocks of distant localities is probably a very rare occurrence, and one which would be very difficult to prove. In speaking of the contemporaneous rocks, therefore, of two localities, the student must be prepared for a sufficiently lax use of the term to include great periods of time. Beds deposited in the English Channel before the Romans visited Britain, would be looked upon by future geologists as strictly contemporaneous with beds forming now in the Irish Sea, should the two districts become dry land; and past dates, separated by actual periods far more vast than any included within historic times, would be equally looked upon now as contemporaneous; the length of time thus uncertainly determined increasing probably with the distance between the two localities where the rocks were observed.†

* See De la Beche's *Researches in Theoretical Geology*, chaps. xi. and xii.

† Professor Huxley, in 1862, proposed to disuse the term contemporaneity as applied to two distant formations with the same assemblage of fossils, and to use in its stead "homotaxis" (or "similarity of order"), thereby indicating that the order of organic succession is the same at both places, without necessarily implying synchronous growth. He remarks, that "for anything that Geology or Palæontology are able to show to the contrary, a Devonian fauna and flora in the British Islands may have been contemporaneous with Silurian life in North America, and with a carboniferous fauna and flora in Africa."—*Quart. Journ. Geol. Soc.*, xviii. p. xlvi.

These principles have always influenced me from my earliest geological days. In speaking of the Coal-measures of Newfoundland, in my report * on the geology of that country, I limited myself to calling them the *Newfoundland Coal-measures*, leaving their identity, or otherwise, with the Coal-measures of other districts, an open question. Not having found any fossils in them in my necessarily hasty search, the Newfoundland Coal-measures might be Tertiary rocks for anything I could say to the contrary. Similarly, in speaking of the Palæozoic rocks and fossils of Australia, I preferred always to speak of them only as Palæozoic, and forbore to discuss the question of their identity in time with the Silurian, Devonian, or Carboniferous periods of Europe, for which even the identity of one or two species (if it occur) is not altogether sufficient evidence. †

Necessity for settling the Chronological Classification of each large Area separately, before forming one for the whole Earth.—It follows, from what has been stated, that in order to avoid error, each great district of the earth, such as Europe or North America, should be surveyed separately, without reference to anything out of the district, and that the order of superposition of its strata, and their classification into groups or formations, should be settled independently, on evidence to be found in that district only. When this has been done, the two series may then be compared, and the synchronism of different parts of each may be decided on.

Western Europe (Britain, France, and Germany), but England more especially, affords an admirable type of a geological district, from the examination of which a chronological scale of classification can be constructed, with which to compare the series of rocks in other parts of the world. Care must however always be taken, that this comparison with British or European formations be not pushed too far, until the district to be compared has been worked out thoroughly on its own independent evidence. The British scale of rocks, although the most complete anywhere yet known within any one district of anything like equal extent, must not therefore be assumed to be perfect, or to be absolutely, instead of comparatively, complete. The series of formations even in Britain is full of gaps, which are known and acknowledged; those which are still unsuspected are probably still more numerous. Many of the formations, or groups of stratified rocks in other parts of the world, which were at one time thought to be contemporaneous with British formations, are now known, or believed, to be more or less intermediate between them; or, to drop the term "contemporaneous," the *homotaxis* or general order of succession is

* *General Report of the Geological Survey of Newfoundland during the years* 1839 *and* 1840. Murray, 1842.

† See *Sketch of Physical Structure of Australia* (Boone), pp. 21, 22.

more complete in the one case than in the other. This intercalation of periods of formation in different parts of the earth, and even in different parts of the same district, will probably have to be still more extensively employed hereafter.

Classification of Groups of Beds by means of their Fossil Contents.—If we take the British Islands or any other good typical portion of the earth's surface, and examine its subterranean structure, we shall find that it is made up of a vast series of variously inclined strata, which appear at the surface in consequence of their "rising" or "cropping" out, one from under another. This great series is not a continuous succession of beds, neither are the beds all of one kind. The occasional breaks in the position, and the changes in the lithological characters of the beds, have afforded geologists the means of separating the great series into groups, to which special names have been given. Most of these groups contain fossils, some of them most abundantly, large parts of them even consisting entirely of organic remains. It is obvious that in such a series of groups the lowest must be the oldest or first formed, and that as they were deposited in succession one over the other, the newest must be the uppermost.

Now it has been discovered that each of these great groups has an assemblage of fossils peculiar to it; so that the general assemblage of fossils found in one group is not found in any other group, either above or below. As minor exceptions to this rule, particular species of fossils seem occasionally to range into two, or perhaps even three adjacent groups, occurring perhaps in the upper part of one group, ranging through the whole of the group above it, and appearing in the lower part of the group above that. Some species, on the other hand, are found only in a very small part of one group, either throughout the lateral extension of the beds wherever they occur, or sometimes limited to some small locality in those beds. What is true of individual species is true also, with a more general and wider application, of the genera and families into which these species are grouped for classification.

When a single species occurs abundantly in one or two beds throughout their extension, we may, if we find it convenient, make a sub-group of those beds, and give them a distinct name, taking the occurrence of this species as their characteristic. Such a small set of beds, whether its characteristics be thus palæontological or merely lithological, is often very useful as giving us a "horizon," and enabling us to determine which are the beds above and below it wherever we find a portion of the set exposed.

When a single species, or an assemblage of several species, occurs in a group of rocks, whether large or small, and has never been found except in that group of rocks, and is almost always found wherever the group extends, we may speak of these as the *characteristic species* of the

group. It occasionally happens that the fossils of such a group are so nearly allied biologically that naturalists form them into a genus, or into one or two genera, which may then be spoken of as equally characteristic. Sometimes a genus, or one or two genera, will range through several adjacent groups of strata, and these groups may themselves admit, either from these palæontological or from other characters, of being classed together as a larger and more general group. In this way we have single beds, sets of beds, sub-groups, and groups of beds, and these are spoken of as "formations" or "systems," according to the importance attached to their characteristics by their describer, or by geologists generally.

It follows, from these statements, that when the order of succession in the groups of rocks has been established by direct observation in one district, and the characteristic fossils of each group have been examined and described, these fossils may be used to identify the groups in another district, where perhaps their order of succession is not open to direct observation. It also follows that, having thus once established the order of succession of the different forms of organic beings in one part of the world, we are able to compare with each other the rock-groups of widely-distant parts of the earth, and approximately establish the homotaxis, if not the contemporaneity, of those which contain similar organic forms.

Law of Approximation to Living Forms.—If we walked attentively through a museum in which there is a tolerably complete collection of characteristic fossils derived from the principal groups of stratified rocks of one district, and these fossils are arranged as assemblages in the order of superposition observed by the rocks from which they were taken, we could hardly fail to arrive at some such conclusions as the following :—

The shells, the crustacea, echinodermata, and corals, from the uppermost or newest rocks, would seem quite familiar to us. Some of the forms might be absolutely identical with those of species now living, and even those which we could not identify with any that we knew anywhere living would still have a familiar aspect, and closely resemble some living forms. If we then continued our inspection in descending order through the different assemblages of fossils brought from lower and lower (*i.e.* older and older) groups of strata, the forms of life would become more and more strange and unfamiliar to us. This strangeness would be more striking in proportion as our knowledge of living forms was accurate and exact. The conchologist, supposing him to have never seen fossil shells before, would be at once able to declare the generic names of those coming from the newer formations, even if the species were new to him. He would say "This is a Volute or a Cone, this is a Venus or an Arca, although," he might add, "I never saw one before

having that precise form and those specific characters." But as he traced the series towards the older groups, not only would he find the species of still existing genera becoming stranger and stranger, but he would find more and more forms to which he could give no generic names at all. He would have to invent new designations, and to define or describe new generic groups in which to place these older shells, so greatly would their characters diverge from any of the descriptions or definitions of recent shells. The professor of all other branches of Natural History would find himself in precisely similar circumstances.

The conclusions to be drawn from these facts are best stated in another and more natural way. The animals and plants living in the earlier periods of the earth's geological history were very different from those which now exist upon the globe; and there has been during all succeeding time a succession of fresh species, showing a gradual approximation in form to those which now exist. Not only did the older species perish one after the other, but most of the older genera, some families, and even a few orders, have died out, while those that succeeded them from time to time showed forms which, with many occasional deviations, gradually grew more and more like those that now live. One or two species came at length into existence which still survive, and these *recent* species became more and more numerous until we arrive at the existing population of the earth. The extinction of species is still going on, man himself being now the most active exterminator. Whether new species have come into existence, since the introduction of man himself, is a problem of which a solution is, at present at least, impossible.

It appears from the above statement that the existing species of animals and plants came into being slowly and gradually; but not only was this the case with the species now living, but it must have been always the case at every period of the earth's history. The law of succession of species reigns throughout. Had any intelligent being lived in one of the later Palæozoic or earlier Secondary periods, he could have stated his palæontological researches in the same terms we ourselves use. The now extinct organic assemblages of that period would then have constituted the "existing" or "recent" species, and ample evidence would have been found in the then recently deposited rocks (most of which have been long ago destroyed), of the gradual coming in of those species, and of their mingling with species which had then become recently extinct in rocks deposited just before the commencement of the period.

Duration of Species proportionate to their Place in the Scale of Existence.—It is an obvious truth that the lowest forms of animal life are the most abundant, and this abundance increases in proportion to their minuteness. It will follow from this that small forms, low in the

scale, will last longer than higher and larger forms, in consequence of their multitude being so great as to render it difficult for any hostile circumstances to exterminate them. This is in harmony with the facts that some species of foraminifera now existing are the oldest of existing species ; that the species of mollusca are longer lived than those of fish, and much longer than mammalia ; and that the species which range through two or three groups are rarely higher than brachiopoda, or some class of similar rank.

Forms once Extinct never re-appear.—It is also certain that species which have once become extinct have never been again brought into existence ; and this is true also of groups of species (genera, families, orders). There is no known instance of any specific form which has once fairly died out ever making its appearance again in the deposits of any subsequent period ; and this is true of many groups of allied forms. There are no Graptolites in rocks more recent than the Silurian, no Trilobites in any rocks more recent than the Palæozoic, no Ammonites in any rocks more recent than Cretaceous, and so on. Nevertheless some genera, such as *Lingula* and *Rhynchonella* among brachiopodous bivalves, and *Nautilus* among cephalopods, have survived, as *genera*, through a long succession of species, from the earliest known ages down to the present day. These are called by Professor Huxley " persistent types."

Supposed Destruction and Sudden Introduction of Assemblages of Species a Mistake.—Some geologists, trusting to the fact that small groups of beds can in some cases be found resting directly one on the other, and containing different groups of fossils, supposed that this must have been in each case the result of the sudden and wholesale destruction of one race of animals and plants, and the wholesale introduction of a new race. This supposition rested on the entirely unwarrantable assumption that these groups of beds were deposited in those localities, not only consecutively, but with short absolute intervals of time between them. Wherever we get a great formation, or system of formations, such as the Carboniferous system of the British Islands, and are able to trace it over a considerable area, and study all its varieties of interstratification of groups of rock, we find the same characteristic species or assemblages of generic forms ranging throughout a great part or the whole of its strata. We may find the characteristic plants in the lower part of the formation in some localities, while in others they may be confined to the upper parts, and conversely we may get the animal remains which are usually confined to the lower parts, making their appearance also in the upper parts wherever circumstances were favourable to their life, and to the preservation of their remains after death. We are, therefore, perfectly warranted, by those positive evidences in its favour, in taking as a rule the great duration, and the

slow and gradual extinction of any fauna and flora. When we meet, on the other hand, with rapid changes in the fossil contents of sets of a few beds resting on each other, the legitimate conclusion is, that in that particular locality only a few beds happened to be deposited during each of the great periods which elapsed while those successive fauna and flora inhabited the earth. When the beds are carefully examined and widely traced, this conclusion is always supported, either by physical evidence proving the discontinuity of their deposition, or else by finding other areas in which the small sets of a few beds expand into great formations.

Untrustworthiness of Negative Evidence in Palæontological Speculations.—Arguing from what we now know, it appears that the earliest life on the globe, during the Laurentian period, was that of large reef-building foraminifera. It seems very difficult to suppose that these existed by themselves. Animal life now is bound together by links, uniting species to species in such a way that, if you destroy one, you in all probability exterminate another which in some way depended on it, and it seems, therefore, almost an impossibility to imagine a world inhabited by only one or two species of animals. Waiving that consideration, however, we have in at least the closing records of the next period certainly a variety of crustacean and molluscan life, while in the succeeding or Silurian period we find remains of fishes, and then of reptiles in the Devonian, or at least in the Carboniferous. Still, in all the Palæozoic series of rocks, there has yet been no trace found of a mammal or a bird. In the very lowest subdivision of the Mesozoic series, however, namely the Trias (though in its upper part, which is called the Keuper), the tooth of a mammal has occurred, and in some still newer rocks the tracks of gigantic birds and the jaws of several mammals.

Now, it may be that we have in these facts a true picture of the course of creation; that during the earlier Palæozoic periods no Vertebrata existed; that at length fishes and then reptiles were introduced, but that long ages still elapsed before birds and mammalia were placed upon the globe. On the other hand, this *may be* only the apparent, and not the real course of creation; it may appear to us so, solely from the deficiency and imperfection of our records. A single discovery of a fish-scale or a fragment of a reptile in the Lower Silurian or Cambrian rocks would greatly damage the hypothesis; a tooth of a mammal in the Palæozoic rocks would upset it altogether. Negative evidence should never be taken at more than its true value, and the process requires to be indeed an exhaustive one before the non-existence of a thing can be held to be established, because we have not yet been able to find it.

The existence of Mammalia in the Secondary rocks was long combated. First one or two, and then five small under jaws were found in the Stonesfield Oolite

At first these were supposed to be marsupial only, that is, to belong to the lowest of the Mammalia; then Professor Owen showed that one at least, the *Stereognathus ooliticus*, was a placental mammal, probably one of the non-ruminant Artiodactyla, and therefore of the same division as our hippopotami and swine; another placental mammal, *Spalacotherium*, one of the Insectivora, was found in the Purbeck rocks; and eventually, by the labours of Mr. Brodie and Mr. Beckles, no less than twelve or thirteen new species of mammals were found in the same formation. These were determined by Professor Owen and Dr. Falconer to belong to eight or nine genera, *Triconodon*, *Plagiaulax*, etc., some marsupial, others placental. They were all found in one bed not more than six inches thick, and within a space of twenty-two yards square. Sir C. Lyell remarks on the bearing of these discoveries on the value of negative evidence, as follows:—The Purbeck rocks "have been divided into three distinct groups by Forbes, each characterised by the same genera of pulmoniferous mollusca and cyprides, but these genera being represented in each group by different species; they have yielded insects of many orders, and the fruits of several plants; and lastly, they contain several 'dirt beds,' or old terrestrial surfaces and soils, at different levels, in some of which erect trunks and stumps of Cycads and Coniferæ, with their roots still attached to them, are preserved. Yet when the geologist inquires if any land animals of a higher grade than reptiles lived during any one of these three periods, the rocks are all silent, save one thin layer of a few inches in thickness; and this single page of the earth's history suddenly reveals to us, in a few weeks, the memorials of so many species of fossil mammalia, that they already outnumber those of many a subdivision of the tertiary series, and far surpass those of all the other secondary rocks put together!"

Such a thin seam, one of those small exceptions in the great series of aqueous rocks, which contains the remains of land animals, might lie hidden for centuries even in the formations which are most searched by the quarryman, miner, and geologist, or might be frequently passed through by the two former, without having been sufficiently examined by the latter. Great as have been the labours and researches of geologists hitherto, we can only look upon them as but having made a commencement, and laid the foundation for more complete discoveries being made in the future.

Application of the Hypothesis of "Natural Selection" to Palæontology.—Mr. Darwin's hypothesis, that varieties are incipient species, or any other reasonable hypothesis, of the slow and gradual evolution of species from preceding species, would agree well with the known facts, whether palæontological, lithological, or petrological, that we meet with in investigating the structure of the earth's crust. There are two classes of facts in the study of fossils which would be naturally explicable on such a hypothesis, and seem difficult to account for without it.

1. It is of course impossible to apply the test of sterility or fertility to the study of fossil species. The palæontological biologist is reduced to the comparison of forms only, often merely of parts of forms. The difficulty of distinguishing between species and varieties presses, therefore, still more strongly on him than on the biologist, who studies living beings only. This difficulty occurs to the palæontologist when studying a number of fossils derived from the same bed of rock, and which were therefore all contemporaneous with each other. But

when he has a great series of beds to deal with, and to trace one or more species throughout this series, he meets with another phase of the difficulty. Certain forms may be met with in the lower beds that seem to be perfectly distinct species from others in the upper beds, although allied to them, but he will in some cases meet with intermediate gradations of form in the intermediate beds, and is therefore compelled to look on those as mere varieties of one species, which he previously considered to be undoubtedly two distinct species. How is he henceforward to be sure that other forms quite as specifically distinct, and derived from different sets of beds, would not graduate into each other as insensibly if he could find the beds which were deposited in the interval between these two sets, and they happened to contain the required fossils? If species be merely the descendants of other species, the existence of intermediate forms of gradation is a necessary and unavoidable consequence, and instead of being a difficulty, is always to be expected.

The hypothesis of descent, again, at once gives us a natural explanation of the law of approximation to living forms, and conversely, the existence of that law, which is one that cannot be gainsaid, lends a strong support to the idea of such a hypothesis, and seems imperatively to demand it. The one appears to be the natural result of the other.

This hypothesis, moreover, gives a natural explanation of the fact of the non-recurrence of species that have once become extinct.

2. There is another class of facts in palæontology which lend a strong support to Mr. Darwin's hypothesis, or at all events to the hypothesis of existing species being connected with extinct by way of descent. The geographical distribution of species at the present day seems to be the direct result of a preceding geographical distribution. The sloths and armadillos and ant-eaters now living in South America were preceded by extinct species of animals belonging to the same orders, some of which extended over parts of North as well as over South America, but none have been found beyond those limits. The extinct kangaroos and wallibis of Australia seem to have been the progenitors of the present races. The giraffe, the hippopotamus, the rhinoceroses, and the pigs of the Old Continent were preceded by species, now extinct, more or less closely allied to them, and no fossil species of those genera has yet been found in America. On the supposition of every distinct species being an independent creation, this geographical limitation of a succession of allied species is unintelligible, but it would be the obvious result of the evolution of one species from another.

Evidence from Palæontology as to the Value of Geological Time.—The fact that vast periods of time must have been necessary for the accomplishment of such a history of life as that which is recorded for us in the rocks, harmonises well with all the other facts of geology.

The more we investigate the formation of rocks, the relations of rock-masses, the contents of mineral veins, and all other inorganic phenomena, the clearer becomes our power of realising the vastness of the periods of time which unroll themselves, fold after fold, before the strained and aching mental vision. That the organic phenomena of the past should require similar enormous intervals of time for their elaboration, seems fitting to the mind of a geologist, and completes, as it were, the harmonious concord of nature's great poem.

It has been already pointed out, however, that the inordinate demands too often made by geologists upon the eternity of the past are not warranted by many of the facts to which they most confidently appeal in their support.* Another common line of argument in favour of these enormously protracted periods is based upon the facts of palæontology. It may be conceded, that "under any view of the origin of species, a long time must needs be demanded for the appearance and disappearance of successive tribes of plants and animals. And the palæontologist may naturally demur to any explanation of geological phenomena which would deprive him of an appeal to unlimited time for the past development of life upon the earth. I cannot but think, however, that such reluctance would mainly arise from the difficulty of adequately conceiving the length of even comparatively brief periods. When a sum rises above a few hundreds of thousands the mind ceases thoroughly to realise it, and each successive cypher which may be added produces no corresponding impression upon us.† Probably the palæontologist would find that the periods, as defined by purely physical evidence, would still remain quite vast enough for the accomplishment of the long history of life. Nor must he forget that changes in the organic world must be to a large extent regulated by those of the inorganic world. If, therefore, we could show conclusively that physical changes in past time advanced more rapidly than had been supposed, it would be necessary to consider whether the periods demanded for the growth and extinction of species and genera might not have been likewise exaggerated. From the data furnished by the denudation now in progress, it seems tolerably certain that geologists have required, for the accomplishment of past denudations, periods of time much greater than our experience of the present economy of nature warrants. It might be well, therefore, if the palæontological argument were re-examined, with the view of ascertaining whether the intervals of time, which it postulates, might not all be easily comprised within the limits required by physical data." ‡

Evidence from Palæontology as to former Changes of Climate.—It is almost solely from the nature of the animals and plants which

* See *ante*, p. 445. † See Mr. Croll's paper in *Phil. Mag.* for May 1868.

‡ Geikie on Denudation, *Trans. Geol. Soc. Glasgow*, iii. p. 189.

have left their remains in the rocks, that we can draw any certain conclusions as to the kind of climate possessed by different parts of the earth where those animals and plants lived. When we find in the British Islands the remains of crocodiles, turtles, and large nautili, together with palm fruits and other tropical-like plants, we cannot resist the conclusion that the climate of the British Islands must have formerly been more like that now found within the tropics than that which they at present possess. It is true that the plants and animals are all of different species from those which now exist, and by the fact of the mammoth, or fossil elephant, and one of the fossil rhinoceroses, having been provided with woolly coats covered with long hair, which fitted them to live in much cooler climates than any existing species of elephant or rhinoceros, we are taught not to rely too implicitly on mere analogies of form; still the fact of the whole assemblage of the fossils of certain great groups of rock being stamped with a tropical "facies," is very strong evidence in favour of their having enjoyed a tropical climate.

But we may extend this argument to still higher latitudes. By the zealous and enlightened labours of our arctic navigators, especially those of Sir Leopold M'Clintock, of Sir E. Belcher, and others of late, and of Parry formerly, we have been put in possession of the very remarkable fact that in latitudes where now sea and land are buried in ice and snow throughout the year, and there are several months of total darkness, there formerly flourished animals and plants very similar to those living in our own province in corresponding geological periods; and it would appear that similar animals and plants were then widely spread over the whole world. There are large tracts of country lying between 73° and 76° of N. lat., and 84° and 96° of W. long., in which the rocks contain Upper Silurian fossils. In the same latitudes, but extending farther west, beds of coal, with Carboniferous plants like those of Europe, were found; and still farther north and west, extending up to 77° 20′, or thereabouts, are limestones full of Carboniferous corals and shells (*Orthoceras*, etc., as well as *Brachiopoda*), while in Prince Patrick's Island, at Wilkie Point, in lat. 76° 20′ N., and long. 117° 20′ W., Oolitic rocks containing an Ammonite (*Ammonites M'Clintocki*), like *A. concavus*, and other shells, were found by M'Clintock; and, moreover, from Exmouth and Table Islands, lat. 77° 10′, long. 95°, part of an ichthyosaurus was brought by Sir E. Belcher.* These facts, all pointing in the same direction, compel us to believe that, during at least a part of the primary, secondary, and tertiary periods, the general climate of the globe was higher and more equable than at the present day.

* See *Fate of Franklin, and his Discoveries*, by Captain Sir F. L. M'Clintock, and *Appendix* by Rev. Professor Haughton.

On the other hand, there is good evidence, from fossil remains, that not only over the northern temperate regions, but as far south as the Himalayah Mountains at least, the climate was once more cold and severe than it is at present. The seas were encumbered with icebergs and the land with glaciers far beyond the limits to which glaciers and icebergs now extend, while the rein-deer, musk-ox, mammoth, and woolly rhinoceros, wandered far south over central Europe.

Such changes of climate must be largely due to the varying position of the earth with reference to the sun, owing to the eccentricity of its orbit, as Mr. Croll has recently pointed out,* and as will be more fully referred to in a subsequent chapter. They may also arise in part from changes in the distribution of sea and land, though not to the extent often supposed. Ocean currents are the great distributors of temperature, and whatever tends materially to modify them must greatly influence climate.†

Practical Importance of Fossils.—The importance of the study of fossils to all those who wish not only to learn the past history of life upon the globe, but to understand the problems involved in its present multiplicity of form and variety of diffusion, will be obvious even from the foregoing slight and general observations. Their importance, however, is not limited to the theoretical speculations, or the philosophical conclusions which may be derived from them, for, like many other scientific conclusions, they may be coined into actual money, or money's worth, by their practical application.

If in any particular part of the earth, beds of any substance of economic value to man were formed during a particular geological period only, it is obvious that these beds will contain the remains of the animals and plants which lived during that period, and no others. If, therefore, the valuable beds be but a few thin seams occurring here and there in a great series, and our object be to discover where any part of that series reaches the surface, in order that we may search for the valuable beds, it is clear that the fossils will be of the greatest assistance to us. The mere lithological character of the other beds of the series may be of little or no use to us as a guide, and may even mislead us, since there may be other groups of rocks of similar character, but not containing the valuable beds.

* *Phil. Mag.* for August 1864, and his papers on Climate in the same Journal, for succeeding years.

† See Professor Hennessy's "Remarks on Terrestrial Climate," *Atlantis*, January 1859. He says that the mean temperature of the earth would not be raised by more land existing at the tropics, since, though the land becomes hotter during the day it gets colder during the night than the sea does, and that more heat would be *conserved* by a general tropical sea than by a general tropical land. Compare also the discussion of this subject by Sir Charles Lyell (*Principles*, vol. i. chaps. xii. xiii.), who attributes extreme importance to the position of land round the equator as a cause of raising the temperature of the globe, and of land at the poles as diminishing it.

The most striking instance of what is here stated generally, is the occurrence of beds of coal in the part of the geological series which is hence called the Carboniferous system. Coal is not confined to that formation, since in different parts of the world good workable coal occurs in other formations; but in Britain and Western Europe, although thin beds of coal occur in other formations, extensive seams of workable coal have only been found in the Carboniferous system. Coal is usually associated with black and grey shales in that system, and the same association occurs in other formations, where the coal is too impure or in too small quantity to be valuable. Black and grey shales also occur in parts of the Carboniferous series, where there is no coal, and in other formations entirely devoid of coal. The coal-miner being always accustomed to see coal associated with black and grey shale, and not having had occasion, like the geologist, to see similar shales in other formations, naturally looks upon the occurrence of the black and grey shale as indicative of the presence of coal. The geologist, on the other hand, having a wider experience, knows that not only do black and grey shales occur where there is no chance of coal being found, but that even thin seams of coal occur in formations where no coal worth working has ever been found in the British area or in Western Europe. He therefore knows that, as a rule, all "indications" are worthless as evidence of the presence of the "Carboniferous formations," except the occurrence of the "carboniferous fossils." Even where the fossils occur there may be no coal, but all search for coal in beds containing any other than the Carboniferous fossils is pure waste of labour and money.

Within my own experience large sums of money have been absolutely thrown away, which the slightest acquaintance with palæontology would have saved. I have known, even in the rich coal district of South Staffordshire, shafts continued down below the Coal-measures, deep into the Silurian shales, with crowds of fossils brought up in every bucket, and the sinker still expecting to find coal in beds below those Silurian fossils. I have known deep and expensive shafts sunk in beds too far above the Coal-measures for their ever being reached, and similar expensive shafts sunk in black shales and slates in the lower rocks far below the Coal-measures, where a pit might be sunk to the centre of the earth without ever meeting with coal. Nor are these fruitless enterprises a thing of the past. They are still going on in spite of the silent warnings of the fossils in the rocks around, and in spite of the loudly-expressed warnings of the geologists, who understand them, but who are supposed still to be vain theorists, and not to know so much as "the practical man." *

* I have elsewhere stated my belief that the amount of money fruitlessly expended in a ridiculous search after coal, even within my own experience, would have paid the entire cost of the Government Geological Survey of the United Kingdom. It is a curious perversity of the human mind, that men prefer to take the advice of those whose interest it is to get them to spend money, rather than the warnings of those who can have no interest in inducing them not to spend it.

IV. STRATIGRAPHICAL GEOLOGY

OR

HISTORY OF THE FORMATION OF THE CRUST OF THE EARTH.

CHAPTER XXIX.

PRELIMINARY OBSERVATIONS.

IN the three preceding parts we have been dealing with general principles:—In the first place, we examined the composition of minerals and rocks, and the great structures which are common to rocks of all kinds and of all ages ; in the second, the various agents by which the formation of rocks and other geological changes are brought about ; while in the third, we considered fossil animals and plants in their relations to living beings, and mentioned some of the general facts of distribution observed by them, and general conclusions to be drawn from them. We had frequent occasion to note the vast periods of time required for the production of the different phenomena we met with, but we did not stop to consider the relations of these several periods of time to each other, or to describe in regular order and sequence the events which had happened. This is now what remains for us to do. We have to give a history of the formation of the crust of the earth, by tracing out the order of succession of the different rock groups of which it is made up, noting the causes which operated in their production, and gleaning, from their relation to each other, some notion, perhaps, of what happened in the periods which intervened between the times of their production.

The way in which this knowledge is to be gained will probably be now sufficiently obvious to the student. At page 188, *et seq.*, we saw, that after having acquired a knowledge of the number and nature of a series of beds, by examining a cliff on the sea-shore, or other "section" where they were well exhibited, any little natural or artificial excava-

tion in the interior of the country which enabled us to identify one of these beds assured us of the presence of the rest above and below it. By searching out places where such "sections" are to be seen, and then following the strata by different indications across a district, and identifying them either by lithological or palæontological characters, or by actually tracing their outcrop without losing sight of them, and performing the same process for the sets of beds that successively cover them, or rise up from beneath them, we eventually survey great tracts of country, and arrive at a knowledge of the order and succession of subterranean groups of rock, to a much greater depth than it would be possible to reach by any process of mining or direct excavation.

The history of the formation of the whole crust of the globe, then, is to be learned by piecing together our knowledge of different parts of it, each part being separately investigated, and joined to another by means of some portion or portions that are proved to be common to the two. Suppose, for instance, that the group of beds from *a* to *b* (Fig. 41, p. 187) were seen in one place, and that we there learnt the history of their production, and gained thereby a record of which the earliest portion is contained in the beds at *a*, and the latest in the beds at *b*; and suppose that no beds above *b* were there visible, but that we could either trace *b* into another district, or could identify it there, and that we then found another great series of beds over *b*, and there learnt the history of their production, carrying it on to the beds about *d* for instance; it is clear that we should there extend our record from *a* to *d*, and this we should do, whether or no there may be any one place where the whole series of beds, from *a* to *d*, be simultaneously present.

We might give this history in either of two ways—namely, by investigating or *tracing* it backwards from the present to the past, or by *narrating* it as nearly as possible in the order in which it occurred. I prefer the latter method as the shorter and more intelligible, since it is hoped that the previous parts of this work will have sufficiently prepared the student to understand it. As, however, to narrate this history in full, even so far as it is already known, would require a library rather than a book, what will be here given must be taken as a mere abstract, a chronological table rather than a history, by means of which the student will be able to refer to its proper period any more detailed account of its different portions, which he may either read of or observe for himself.

Even this abstract can only be a very imperfect, broken, and fragmentary one. Comparatively few parts of the earth's surface have as yet had their structure even sketched out; still fewer have been accurately surveyed, and had their details thoroughly unravelled. Many of the events, therefore, which are now supposed to have occurred contemporaneously in different places, may in reality have

occurred in succession; some of those which we imagine to have happened at different times may have been more or less contemporaneous; while many which are supposed to have directly succeeded each other may have been separated in reality by great spaces of time, of which there are no records as yet discovered, or of which none may ever be found.

As the structure of the British Islands is better known than that of any other part of the globe of equal dimensions, and contains a more complete series of rocks in a small space than any other known district, we shall take that as the principal authority for our history, pointing out the several groups of rock which were produced in this part of the globe during the several periods, mentioning a few of the principal fossils they enclose. We shall then give some of those other well-known typical groups of rock which are regarded as contemporaneous or at least homotaxial* with them in other parts of the earth. Where a group of rocks is known of which we have no homotaxial representative in the British Islands, it will of course be best to describe it from its best known locality. Our history, however, will be chiefly that of the formation of the Celtic or British province, as we may call it, with occasional reference to the history of other provinces.

Chronological Nomenclature.—One difficulty meets us at the outset as to our nomenclature, that is, as to the names we are to give to the different periods of past time. This difficulty must at present be evaded, since the time has not yet arrived, that is to say, our knowledge is not yet complete enough to enable us to overcome it.

The early geological observers described certain kinds of rock, to which particular names were given. These names were, in the first instance, lithological, or descriptive of the kind of stone, of which Chalk and Oolite are instances. In other cases they were petrological, such as Mountain Limestone, Coal-measures, etc. Others again were geographical, of which Wealden, Neocomian, Silurian, Oxford Clay, are examples; while others were local terms adopted by geologists, such as Lias, Cornbrash, Gault, etc. Such terms as Old and New Red Sandstone were both lithological and stratigraphical, referring at once to the kind of rock of which the formations were composed, and the relative place of the formations in the series. Gradually, as extended observation showed that aqueous rocks occurred in a certain order, and formed a succession of beds regularly superimposed one upon the other, a chronological sense began to be extended to these terms, for it was clear that each bed, and each group of beds, was newer than those below it, and older than those above it, while those occupying the same place in the series were contemporaneous. Thus, *The Oolite*, and *The Chalk*, came to mean, not only the rocks to which these names were first and truly applied, because they consisted of the kind of stone

* See *ante*, p. 500.

called Oolite and Chalk, but also all other kinds of rock which occupied the same relative place in the general geological series, and contained the same fossils. The Cretaceous or Chalk rocks, then, might be made either of white chalk, of black marble, of brown sandstone, or blue slate; "Cretaceous rocks," meaning in reality only rocks of *the same age* as the Chalk, or at least *homotaxial* with it. Silurian rocks, in like manner, mean those *of the same age* as or *homotaxial* with the rocks of Siluria, and so of the rest. This double signification of words is almost unavoidable, and the student will find himself naturally and inevitably falling into it in the course of his geological pursuits. When, then, we speak of Silurian, or Carboniferous, or Oolitic, or Cretaceous *periods* of time, the reader must pardon the apparent contradiction in the terms, and look on the names as *names only*, and not as descriptive designations. This is indeed what we do in ordinary language, and in human history, since we speak of the Babylonian, the Greek, or the Roman periods, and thus give chronological significations to mere geographical terms.

It is doubtless puzzling enough at first, if we are shown in South America a mountain of blue clay-slate, and told that that is "Chalk;" or, if we find the same term applied, in North America, to a group of sandstones, shales, and coals. Many persons are, in like manner, perplexed when they find, in the British Islands, clay-slate spoken of as "Old Red Sandstone;" but this difficulty vanishes if we recollect that when used geologically these words mean a period of time, and not any particular kind of rock. The term Old Red Sandstone was at first applied to a large system of rocks, of which red sandstones were the most conspicuous portions, although beds of clay, and even thin beds of limestone, as well as beds of white, yellow, or green sandstones, also occurred in it. It was called *old*, because it lay below the Carboniferous rocks, while there was another system of red sandstones which lay above the Carboniferous rocks, and was, therefore, called *new*. But it has been already remarked that formations, when they are traced laterally over large areas, are often apt to change their lithological characters, either in consequence of the gradual termination of one set of beds and the setting in of beds of a different kind, or because they have come within the reach of subsequent influences in one region which did not affect them in another. When then we trace the Old Red Sandstone across a large tract of ground, as we can trace it across the south of Ireland, for instance, we need not feel surprised at its gradually passing from a sandstone formation into a clay-slate formation. As it is possible in Ireland to walk along it from one district to the other without ever leaving it, it is clear that if it ought to be called Old Red Sandstone in the one district, it would be giving two names to one group of rocks, if we gave it another name in the other district.

Whether the name "Old Red Sandstone" be a good one, is another question. It is retained simply because it is generally understood that by that designation we mean the rocks lying next below those called Carboniferous. It is avowedly a "provisional" designation, just exactly as all the names of the great groups of stratified rocks are provisional. They are temporary names adopted for present purposes, and have *grown into use*, and will continue to be used until they are superseded by more appropriate terms, which increasing knowledge only can show to be more appropriate. Many attempts have been made to introduce a more systematic nomenclature; but they have all failed, because the attempt required almost prophetic powers on the part of the inventor, who should know what would be wanted in a few years time, as well as what is wanted now. Any scheme of nomenclature which is not expansible in all directions, and does not admit of re-adjustment and interpolation, according to circumstances in all its parts, will in a short time be found to serve as the fetters rather than the clothes of the science.*

In speaking of the great groups of stratified rocks or "formations," therefore, the student must clearly understand that their names are often used also as the names of the periods of time in which they were formed, and accustom himself to detach from these names all other meanings they may have.

The igneous rocks, however, are named on lithological grounds, although, as has been already pointed out, a broad chronological classification can be made of them. The crystalline aggregate of felspar, mica, and quartz, is called granite, no matter where it was formed, or with what stratified rocks it may be associated. Felstone, greenstone, trachyte, and basalt, and all the other names of igneous rocks, refer in like manner to their mineral constituents and texture, irrespective of the period in which they were erupted, or the part of the earth's crust in which they are found. Among the stratified rocks, also, all names which have a special lithological signification, such as shale, grit, dolomite, magnesian limestone, oolite, etc., are applied to the variety of rock quite independently of any reference to the time when it was produced, or the formation to which it belongs. Any limestone of any formation may become magnesian; any limestone of any formation may become oolitic. It is only when that accidental character has, by use, been applied to some particular group of stratified rocks, which are then spoken of as *The* magnesian limestone, or *The* oolite, that the words acquire a technical chronological signification, that is to say, may

* In the maps and publications of the Geological Survey, for instance, the letter "a" was adopted for the rocks of the Cambrian period, as being the earliest period of which anything was known; the discoveries of Sir W. Logan and Sir R. I. Murchison, have, however, shown us rocks belonging to still earlier periods, and if we wish to letter them on our maps, we find ourselves at a loss for a letter before "a" in the alphabet.

be used to designate all those stratified rocks which are representative of the group to which the name was first applied.

I must, therefore, request the student now to fix his attention chiefly upon *time*, and to suppose that all geological time is divided into three great portions or successions of periods, which we may call Primary, Secondary, and Tertiary.

The Primary periods mean simply those which preceded the Secondary, the first great cycle of time of which we know anything, not by any means the first time of all, since as to that we know nothing. The earliest of Primary periods has no definite starting-point. Future investigations may show us formations lying below those which are the lowest we have hitherto discovered, so that our chronological commencement is lost in the remote past. Geological history can only begin like a fairy tale—"Once upon a time there was a sea, and in that sea certain rocks were formed," and so on. The Secondary periods, in like manner, mean those which succeed the Primary. Geologists agree to draw a line somewhere in the series, and to take that line as the boundary between the Primary and Secondary periods. So with the Tertiary periods, a certain boundary-line is drawn as the close of the Secondary periods, and all time since then is included in the Tertiary periods.*

As synonyms of these words, Primary, Secondary, and Tertiary, the words Palæozoic, Mesozoic, and Cainozoic, signifying the periods of ancient, middle, and modern life, have been proposed by Professor Phillips, and pretty generally adopted. Geological time, then, may be thus arranged :—

III. Tertiary or Cainozoic Periods.†

Human, Historical, or Recent era.
Pleistocene era.
Pliocene era.
Miocene era.
Eocene era.

* The word "period" is used by geologists in a very loose way, to designate any long, tolerably well-marked portion of time. The time during which the Carboniferous limestone was formed, for example, is spoken of as the Carboniferous limestone period; but that time, vast though it was, formed but a part of a far longer interval, during which the rest of the Carboniferous system was formed, and which is termed the Carboniferous period. Then, again, the Carboniferous is only one of several enormous cycles of time, which are comprised within what is often called the Palæozoic or Primary period. It would perhaps be best to restrict the term "period" to express the interval of time required for the production of a system of formations, such as Carboniferous, Permian, Cretaceous, etc., using some other word, such as "age," to denote the subordinate interval occupied by the elaboration of each formation.—Ed.

† The mode of arrangement adopted in this table is intended to indicate that our chronology depends on the fact of superposition of rock groups, and that it therefore commences with the lowest of these groups.

II. SECONDARY OR MESOZOIC PERIODS.

Cretaceous era.
Jurassic era.
Triassic era.

I. PRIMARY OR PALÆOZOIC PERIODS.

Permian era.
Carboniferous era.
Devonian and Old Red Sandstone era.
Silurian era.
Cambrian era.
Laurentian or Pre-Cambrian eras.

Edward Forbes suggested that both from palæontological and petrological considerations, it might be better if we obliterated the division between the Secondary and Tertiary periods, and divided geological time into two periods only, namely, Palæozoic and Neozoic. Perhaps, as our knowledge becomes more complete, this suggestion may be carried out. The most marked characteristic of the Tertiary periods is, that the rocks then deposited contain the remains of species which still exist. These in the earlier Tertiary deposits are very few, and if those few were now to die out and become extinct, the characteristic would be lost, and the palæontological distinction between Secondary and Tertiary deposits become more arbitrary than it is.*

* The student, in reading the older geological works, will meet with other terms than those mentioned above, which it will be as well to explain. An opinion once existed that all such rocks as granite, together with the crystalline schists, such as gneiss and mica schists, were *primitive rocks*, and that the ordinary stratified sandstones, clays, and limestones, were derived from these supposed primitive rocks; they were therefore called secondary, in the sense of derivative, rocks. Extended observation, however, showed a class of rocks with characters apparently intermediate between those which were supposed to belong to these so-called primitive and secondary rocks. For this class the term "transition" was invented. About the same time, the idea of the *primitiveness* of the granites and crystalline schists began to be shaken, and the term primitive was modified into primary. There were also other rocks discovered lying above those which had hitherto been taken as the uppermost of the secondary, and to these the term tertiary was naturally applied. But when granite was found to be not only not a primitive but an intrusive rock, and also not solely intrusive into primary rocks, but intrusive into rocks of almost all ages; and when it was ascertained that the crystalline schists were in reality metamorphic rocks, and that their crystalline schistose character was not peculiar to any geological period, the term "transition" was gradually disused, and the word primary lost the lithological taint which it had derived from its primitive original, and acquired its present purely chronological sense, as simply meaning all rocks older than the secondary.

For convenience of reference it may be useful to give here a Synoptical Table of the various formations into which the deposits of these great Geological periods are divided in Britain.

TABLE OF BRITISH SEDIMENTARY STRATA.

Era	Period	Series	Group	Formations	
POST TERTIARY.	Pleistocene or Quaternary.		Recent and Pre-Historic.	Blown Sand and Shingle.	
				Alluvium and River Deltas.	
				Burtle Beds of Somerset. Scrobicularia Clays.	
				Peat Bogs of Ireland, and Peaty Beds of England.	
			Post-Glacial .	Raised Beaches.	
				Cave Deposits.	
				River Gravels, Brick Earths, and Freshwater Clays, with Mammalian Remains.	
				Kaims or Kames of Scotland.	
				Eskers or Escars of Ireland.	
				Tufa and Shell-marl.	
			Glacial	Drift (Upper Boulder Clay or Till, Marine Gravels, Lower Till and Moraines). Loess of the Rhine, etc.	
			Pre-Glacial .	Forest Bed of Norfolk Shore.	
CAINOZOIC OR TERTIARY.	Pliocene.		Crag	Mammaliferous Crag, Red Crag	Norwich Crag, Newer Pliocene.
				Coralline Crag (Suffolk Crag) (Older Pliocene).	
	Miocene			Leaf-Bed of Mull.	
				Lignite of Antrim.	
				Bovey Beds with Lignite.	
	Eocene.	Upper	Hempstead Beds	Corbula Beds	Fluvio-Marine Series.
				Upper, Middle, Lower — Freshwater and Estuary Marls	Fluvio-Marine Series.
			Bembridge Beds	Bembridge Marls	Fluvio-Marine Series.
				" Limestone	Fluvio-Marine Series.
			Osborne Beds	St. Helen's Sands	Fluvio-Marine Series.
				Nettlestone Grits	Fluvio-Marine Series.
		Middle	Headon Beds .	Upper, Middle, Lower — Headon Beds	Fluvio-Marine Series.
			Bagshot Beds .	Upper Bagshot Sand.	
				Middle " — Barton Clay. Bracklesham Beds.	
				Lower " Sand and Pipeclay, with plants.	
		Lower	London Tertiaries	London Clay and Bognor Beds. Upper London Tertiaries.	
				Oldhaven Beds, Woolwich and Reading Beds	Plastic Clay. Lower London Tertiaries.
				Thanet Beds	
MESOZOIC OR SECONDARY.	Cretaceous.		alk	Upper Chalk, with layers of Flint (Maestricht and Faxoe Beds).	
				Lower Chalk, without Flints.	
				Chalk Marl.	
				Chloritic Marl.	
			. . . . .	Upper Greensand (Fire-stone of Surrey), Malm Rock, etc.	
			. . . . .	Gault (Clay).	
			Lower Greensand, or Upper Neocomian	Folkestone Beds (Sand).	
				Sandgate Beds (with Fuller's Earth).	
				Hythe Beds (with Kentish Rag and Boorgate Stone).	
				Atherfield Clay. Specton Clay.	
			. . . .	Weald Clay (with Sussex or Bethersden Marble and Horsham Stone.)	
			Hastings Sand	Upper Tunbridge Wells Sand, Grinstead Clay, Lower Tunbridge Wells Sand	Tunbridge Wells Beds.
				Wadhurst Clay (with Iron Ore).	
				Ashdown Sands.	
				Ashburnham Beds.	

MESOZOIC OR SECONDARY—*continued.*	Jurassic Series.	OOLITIC SERIES.	UPPER.	Purbeck . .	Upper (with Purbeck Marble) Middle Lower (with Dirt Beds)	Purbeck Beds.
				Portland .	Portland Stone. Portland Sand. Kimeridge Clay (with Bituminous Shale).	
			MIDDLE.	Coralline Oolite.	Upper Calcareous Grit. Coral Rag (with Iron Ore). Lower Calcareous Grit.	
				Oxford Clay	Oxford Clay and Kellaways Rock.	
			LOWER.	Forest Marble	Cornbrash. Forest Marble and Bradford Clay (with Encrinites).	
				Great Oolite	Great or Bath Oolite (with "Fullers' Earth" at base in South of England). Stonesfield Slate, near the base in part of South of England. Northampton Sand (with Iron Ore) in N. Oxfordshire and South Northamptonshire.	
				Fullers' Earth	Upper Fullers' Earth (Clay). Fullers' Earth Rock (Limestone). Lower Fullers' Earth (Clay).	
				Inferior Oolite.	Cheltenham: Ragstone and Clypeous Bed. Upper Freestone. Oolite Marl. Lower Freestone. Pea Grit. Collyweston Slate, at the base of the Limestone in Lincolnshire. Sands.	
		LIAS.		Upper Lias.	Clay and Shale.	
				Middle Lias.	Marlstone (Rock Bed, with Iron Ore, Sand, etc).	
				Lower Lias.	Clay, Shale, and Limestone.	
	Poikilitic Series, or Trias or New Red Sandstone.	UPPER TRIAS.		Rhætic or Penarth Beds	"White Lias," Avicula contorta Beds, with Koessen Beds. Bone Bed of Aust, etc. *St. Cassian and Hallstadt Beds.*	
				Keuper .	Red variegated Marl and Upper Keuper Sandstone (with Gypsum and Rock Salt). Lower Keuper Sandstone and Marl (Water-stones). *Muschelkalk, absent in Britain.*	
		MIDDLE TRIAS.		. . .	Dolomitic Conglomerate, Somerset, Gloucester, and South Wales.	
		LOWER TRIAS.		Bunter .	Upper Red and Mottled Sandstone. Pebble Beds, Calcareous Conglomerate and Breccia. Lower Red and Mottled Sandstone.	
PALÆOZOIC OR PRIMARY.	UPPER PALÆOZOIC.	Permian.		Upper or Magnesian Limestone Series.	? Red Marl with Magnesian Limestone Sandstone. Upper Red Marl Upper Magnesian Limestone Lower Red Marl and Sandstone Lower Magnesian Limestone	Zechstein.
				Lower or Rothliegende.	Red Marl, Sandstone, Breccia, and Conglomerate.	
		Carboniferous Series.			ENGLAND.	SCOTLAND.
				Coal Measures.	Upper Coal Measures Middle Coal Measures Pennant Grit Lower Coal Measures Gannister Beds	Upper Coal Measures.
				. . . .	Millstone Grit, or Farewell Rock.	Moor Rock.
				Carboniferous or Mountain Limestone.	Upper Limestone Shale (Yoredale Rocks) Carboniferous Limestone	Upper Limestones. Edge Coals Series. Lower Limestones.
					Lower Limestone Shale	Calciferous Sandstone Series.

PALÆOZOIC OR PRIMARY—*continued*.

				England.	Scotland.
UPPER PALÆOZOIC.	Devonian and Old Red Sandstone.		Devonian Beds.	Upper Devonian or Barnstaple and Marwood Beds, with Petherwin Limestone in N.E. Cornwall.	Upper Old Red Sandstone.
				Middle Devonian or Ilfracombe Beds, with Fossiliferous Limestones and Cornstones.	Middle Old Red Sandstone.
				Lower Devonian or Lynton Beds.	Lower Old Red Sandstone.
LOWER PALÆOZOIC.	Silurian.	Upper.	. . . .	Tilestones or Passage Beds.	Kirkby Moor Flags.
			Ludlow Beds	Upper Ludlow Beds (with Bone Bed).	
				Aymestry Limestone.	Bannisdale Beds, Flags, Slates, and Sandstone.
				Lower Ludlow Beds.	
			Wenlock Beds	Wenlock Limestone.	
				Wenlock Shale, Sandstone, and Flags.	
				Woolhope Limestone and Shale, and	Coniston Grits and Flags.
				Denbighshire Grits, Shales, Slates, and Flags.*	
			. . . .	Tarannon Shale (Pale Slates).	Stockdale Slates.
			Llandovery Beds.	Upper Llandovery Rock. (May Hill Sandstone.) (Pentamerus Beds.)	
				Lower Llandovery Rocks.	
		Lower.	Caradoc or Bala Beds.	Caradoc and Bala Beds.	Coniston Limestone, Limestone and Shale.
				Sandstones (often shelly), with Bala Limestone, Shale, and Slate.	
			Llandeilo .	Upper Llandeilo Flags and Limestone, etc.	Skiddaw Slates.
				Tremadoc Slates.	
			Lingula Beds	Lingula Flags.	
	Cambrian.		Cambrian .	Harlech Grits, etc.	
				Purple Slates and Grits (St. David's).	
				Llanberis Grits and Slates.	
				Longmynd Rocks.	
				Red Sandstone and Conglomerate (Scotland).	
	Laurentian . .			Fundamental Gneiss of the N.W. of Scotland, etc.	

CHAPTER XXX.

I. PRIMARY OR PALÆOZOIC PERIODS.

LAURENTIAN OR PRE-CAMBRIAN PERIOD.

In geological history, as in the history of most human empires, it is difficult to point out any definite commencement. If we assume a starting-point, we must, of course, allow for great periods of preceding unreckoned time, and for many unrecorded events which led up to those which we are about to describe. The progress of geological investigation has lately disclosed to us some records of a date earlier than had been previously recognised. Sir W. Logan in Canada, and Sir Roderick Murchison in Scotland, with their several colleagues and fellow-labourers, have shown distinctly what was only surmised previously, that certain great masses of highly metamorphosed rocks come out from underneath other masses, which belong either to the Cambrian period, or to an older one.

The labours of Sir Roderick Murchison, aided by those of his colleagues Professor Ramsay and Mr. Geikie, and also by Professor Harkness, have shown that the crystalline metamorphic rocks of the Scottish Highlands consist of two distinct series, one of which consists of altered Lower Silurian strata, while the other is more ancient than the Cambrian rocks, and is parallel with the Laurentian system of Canada.

In the Hebrides, and at different parts along the western shore of Sutherlandshire, great masses of highly crystalline gneiss are visible, often consisting of alternate hornblendic and quartzose folia, but having sometimes felspathic and micaceous layers, with occasional beds of limestone and ironstone. The foliation coincides with the stratification, and the strike of the rocks is N.W. and S.E. (or at right angles to the general strike of other parts of the country), the beds dipping either N.E. or S.W., more frequently the latter. They are here and there traversed by veins of granite proceeding from larger intrusive granitic masses, and also by dykes of greenstone. Upon the highly inclined and greatly denuded edges of these beds, rest, quite unconformably, thick beds of a red sandstone and conglomerate, which is itself covered

unconformably by beds which are proved to be lower Silurian by the fossils they contain. (See diagrammatic section, Fig. 149.) This red

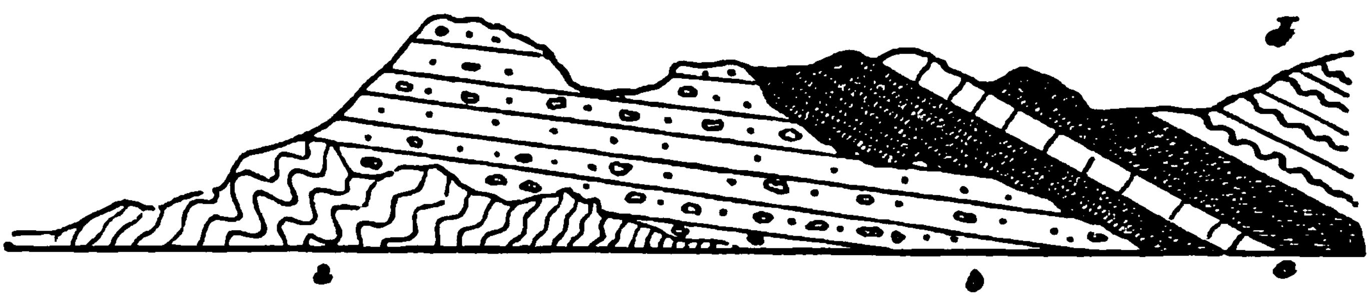

Fig. 149.

Diagrammatic section, showing the geological structure of the northern Highlands.*

d. Lower Silurian, crystalline, gneissose, and micaceous flags. *c.* Lower Silurian, Quartz-rock and Limestone, with *Orthoceras*, *Piloceras*, *Maclurea*, *Ophileta*, *Murchisonia*, and *Orthis striatula* in the limestones, and annelid tubes in the quartz-rock. *b.* Red Sandstone and Conglomerate, 2500 feet thick, formerly supposed to be Old Red Sandstone, now seen to be Cambrian. *a.* Laurentian gneiss, with granite veins, etc.

sandstone and conglomerate then must be either Cambrian or some still older deposit, and the gneiss formation below it must certainly be of pre-Cambrian age. Sir R. I. Murchison at first described it as Fundamental gneiss, a term which could only be accepted as applicable to Scotland, since still lower rocks may hereafter be seen in other districts. In the last paper by himself and Mr. Geikie, he considers it as contemporaneous with Sir W. Logan's Laurentian gneiss, and speaks of it by that designation. This parallelism is of course merely an inferred one. The oldest gneiss of Canada and the oldest gneiss of Scotland are *homotaxial*—that is, they occupy the same place in the succession of formations, as at present ascertained; but it is quite possible that the one was formed in a very different stage of the world's history from that in which the other was deposited.

Foreign Localities.

Canada.—Sir W. Logan and his colleague Mr. Murray have described in North America a vast series of rocks, once ordinary sedimentary strata, but now contorted and highly metamorphosed and crystalline, to which they have given the name Laurentian, from the great development of these rocks along the country drained by the St. Lawrence. †

There is a Lower Laurentian gneiss series, with an Upper Laurentian gneiss unconformably covering it, their joint thickness being certainly not less than 30,000 feet. The upper series consists in large measure of various felspar-rocks, including varieties full of hypersthene, and some mainly composed of largely crystalline labradorite. The Lower series is chiefly an orthoclase gneiss. Both

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* See Murchison, *Quart. Journ. Geol. Soc.* xv. p. 353; xvi. p. 215; Nicol, *Op. cit.* xiii. p. 17; Murchison and Geikie, *Op. cit.* vol. xvii. p. 171; and their *Geological Map of Scotland.* Harkness, *Quart. Journ. Geol. Soc.* vol. xvi. p. 312.

† See Sir W. Logan's *Geology of Canada*, and *Quart. Journ. Geol. Soc.* xxi. 45.

of them contain "several zones of limestone, each of sufficient volume to constitute an independent formation," three of which, at least, belong to the Lower division. The existence of these limestones in gneissic rocks seems conclusive proof of the existence of animal life in sufficient abundance to form such calcareous masses. The organic origin of the limestone has been confirmed by the discovery in that rock of a large foraminifer, named *Eozoon Canadense.* *

Scandinavia.—It is probable that the highly metamorphosed rocks, which form the mountains of Norway, belong wholly or in part to the Præ-Cambrian periods. An *Eozoon* has been found in the limestone of a gneiss series (believed to be Laurentian) in Finland. †

Bohemia and Bavaria.—A formation of gneiss with associated limestone, believed to be of Laurentian age, has been found in these regions. The limestone has yielded two foraminifers allied to the Canadian species, and called respectively *Eozoon Bohemicum* and *E. Bavaricum.* ‡

Future research will probably show the existence of other pre-Cambrian metamorphic rocks in other parts of the world, perhaps in South America, for instance, or Australia, or parts of Africa and Asia, where metamorphic rocks are now known to exist, or may hereafter be discovered, but of which the true geological horizon has not yet been ascertained. We can indeed never hope to discover the unaltered deposits of the earlier ages of the earth's history. The first-formed aqueous rocks have doubtless long ago perished utterly, either from erosion by water or from having been re-absorbed into the molten interior of the earth. The oldest sedimentary rocks now left anywhere upon the globe must necessarily have suffered more from these two actions than any newer rocks. The Laurentian system is the oldest we have yet discovered, but its records are nearly obliterated, and their history, therefore, very obscure.

CAMBRIAN PERIOD.

WALES AND SHROPSHIRE.—The lowest rocks visible in North Wales and its borders having been called *the Cambrian* rocks, the period in which they were deposited may be called provisionally the Cambrian period. These rocks may be seen largely developed in the hilly ground between Harlech and Dolgelli, in parts of Caernarvonshire west of the Snowdon crest, and in Anglesea, where, however, they are much metamorphosed into chloritic schists and quartz rocks. They are still more largely exposed in the Longmynd, a range of hilly ground to the north-west of Church Stretton in Shropshire. The following succession of Cambrian beds is described by Mr. W. T. Aveline, the thicknesses being of course approximate, but on the whole nearly correct :— §

* See the descriptions given by Drs. Carpenter and Dawson of this fossil in *Quart. Journ. Geol. Soc.* xxi. 51; xxii. 219; xxiii. 257; *Intellectual Observer,* No. xl. p. 300; also Murchison's *Siluria,* p. 12. The organic origin of *Eozoon* has been disputed by Messrs. King and Rowney, *Quart. Journ. Geol. Soc.* xxii. 185.

† See Murchison, *Siluria,* p. 550.

‡ See Murchison, *Siluria,* p. 372 and references, and the first volume of the *Landesdurchforschung von Böhmen,* sect. ii. pp. 245-56, where a nature-print and coloured lithographs of *Eozoon Bohemicum* are given.

§ Sheet 36 of Horizontal Sect. of Geol. Survey of Great Britain.

	Feet.
Coarse red sandstone	7000
Red sandy micaceous shale	300
Hard coarse red sandstone and shale	4500
Hard gritty grey sandstone	1500
Purple sandy shale	100
Reddish-brown coarse sandstone	2000
Purple shale and sandstone	4000
Grey rock, very hard	1000
Hard conglomerate	200
Hard sandstone	400
Greyish-blue slaty shale	2000
No base seen	23,000

The position of these rocks, with regard to the overlying formations, is shown in Fig. 150.

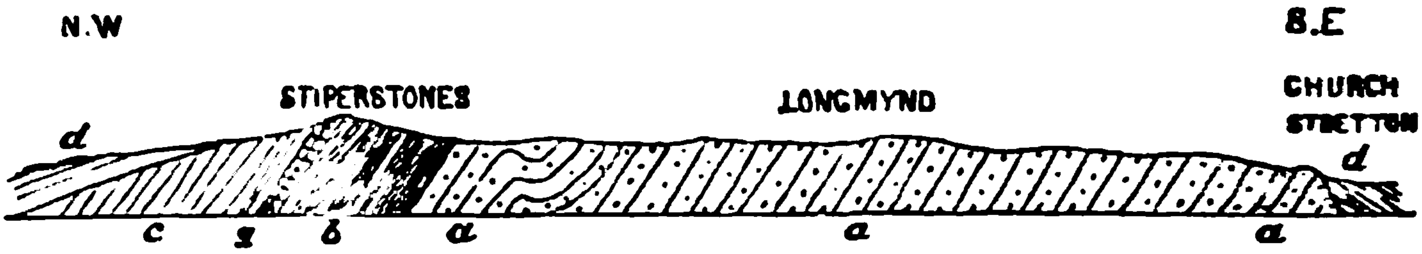

Fig. 150.

Section across the Longmynd, reduced from Sheet 36 of the Horizontal Sections of the Geological Survey. Length of section about nine miles.

d. Upper Silurian (Wenlock shale and Llandovery sandstone).
c. Llandeilo flags. } Lower Silurian.
b. Lingula flags. }
a. Cambrian grits and slates.

In another section, likewise drawn by Mr. Aveline, the succession of strata is generally similar, but exhibits an apparent thickness of 28,000 feet.* In one drawn by Mr. Selwyn, across the country between Harlech and Dolgelli, are shown 8000 feet of thick beds of hard grey and greenish-grey quartz rock, sandstone, and blue, green, and purple clay-slate, the lower part of the series not being seen.† In yet another section, drawn by Professor Ramsay, from the Menai Strait over Glyder Fawr to the north of Snowdon, the upper 5000 feet of the Cambrian series are represented as consisting of green and purple slates, grits, sandstones, and conglomerates, the pebbles in the latter consisting of quartz, quartz-rock, purple sandstone, blue slate, black slate, quartziferous porphyry, and green jasper.‡ The Penrhyn and Llanberis slate-quarries are worked in a band of slate, in the upper part of this series.

According to the researches of the late Mr. Salter and Mr. Hicks, the Cambrian series, as developed in Pembrokeshire, is divisible into two groups—1st, the lower or Harlech group, consisting of purple and

* Sheet 34 of the same series of sections. † *Op. cit.* Sheet 37. ‡ *Op. cit.* Sheet 31.

greenish-grey sandstone ; and 2d, the upper or Menevian group, about 1500 or 1600 feet thick, consisting of dark flags and shales, and covered by the Ffestiniog group or Lingula flags of the Lower Silurian series.

SCOTLAND.—The only rocks in Scotland which can be assigned to this system are those which, from Cape Wrath southward into Applecross, lie upon the fundamental gneiss of that region, and are unconformably covered by the lower Silurian quartz-rocks and limestones. They consist of red and purple sandstones and conglomerates, and are at least 7000 or 8000 feet thick (see Fig. 149).*

IRELAND.—In the northern part of the County Wicklow ; in the hill of Howth, in County Dublin ; and in the Forth mountain district of South Wexford, are great masses of rock, believed to belong to the same series as those just described in North Wales. Like them, they consist of massive beds of grit and slate, of dull green, brown, purple, and liver-coloured hues, but in Ireland they have also many thick, but irregular, and often interrupted, beds of brown and yellowish quartz rock interstratified with them. They are greatly disturbed and confused, so that no continuous section can be followed in them, although single detached exposures show thicknesses of several thousand feet. Bray Head, the Devil's Glen, and the hill called Carrick MacReily, south of that glen, the cliffs and rocks of Howth, exhibit characteristic examples of the rocks, while those of Wexford may be seen on the banks of the Slaney, and on the coast about Cahore Point. Fig. 151 is a section representing the structure of Bray Head.

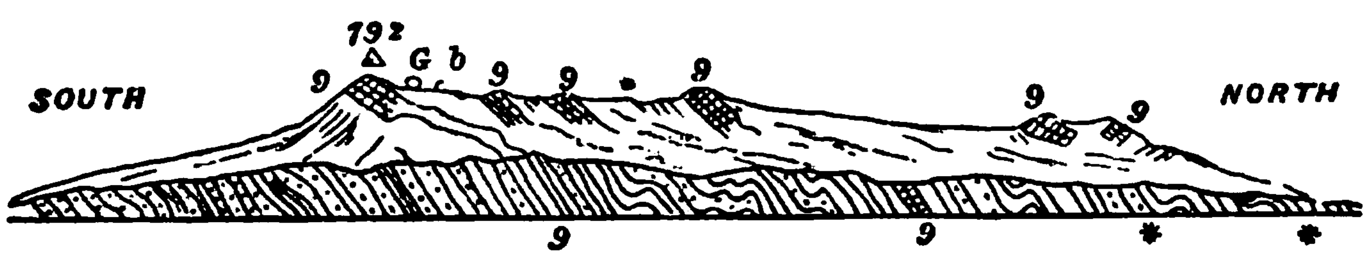

Fig. 151.

Sketch section of Bray Head. Length of section about 2 miles.

9. Quartz-rock. G b. Granite blocks.

Note.—In this figure the lower part is intended to represent the coast section, and the upper part the slope of the hill above it. There are more bands of quartz-rock on the hill-top than appear in the sea-cliffs, but the one which forms the summit, 792 feet, comes down to the cliffs, as indicated by the two lines ; the beds in the cliff were cross-barred in the original drawing, although that character has been omitted in the woodcut.

Characteristic Fossils.—No traces of organic remains, except what have been called fucoid-markings, have as yet been observed in the Cambrian rocks in North Wales. In the Longmynd, however, Mr. Salter discovered on the surface of some of the slabs numerous small pits occurring in pairs, which he believed to be the burrows of small sea-worms, and called *Arenicolites didyma*, and also an obscure impres-

* See the papers quoted in the first note on p. 524.

sion, which he supposed to be that of part of a trilobite, which he called *Palæopyge Ramsayi*, but of which the organic nature is now very generally discredited.

In the Harlech group Mr. Hicks has found at St. David's a tolerably abundant fauna, containing twenty species, referable to seventeen genera, and including trilobites, phyllopods, brachiopods, and pteropods, besides annelid-tracks.* In the Menevian group Messrs. Salter and Hicks brought to light a peculiarly rich fauna, counting more than forty species, among which are included some large trilobites, one of which, *Paradoxides Davidis*, nearly two feet long, is characteristic of the group.†

Fossil Group No. 1.‡—Cambrian Fossils. Ireland.

a. Oldhamia antiqua. c. Histioderma Hibernicum. e. Arenicolites didyma.
b. ——— radiata. d. Annelid? tracks. f. Molluscan? tracks?

Professor Thomas Oldham (now Dr. Oldham, Superintendent of the Geological Survey of India) was the first who noticed in the Cambrian schists of Bray Head, Wicklow, the peculiar markings afterwards de-

* See *Brit. Assoc. Rep.* 1866, p. 66; and Lyell's *Student's Manual*, p. 470.

† See *Brit. Assoc. Rep.* 1865-66-68; and *Quart. Journ. Geol. Soc.* xxi. xxv.

‡ The fractional numbers appended to these figures denote the proportions they bear to the originals, as ⅓, one third, etc. If the highest figure be the numerator, as 3/1, it would mean that the figure was three times the size of the original.

scribed by Professor Edward Forbes as *Oldhamia*, in honour of the discoverer. Of these two species were named *O. antiqua* and *radiata*, Professor Forbes considering them to be allied to Sertularian zoophytes; other naturalists, however, believe them to be plants, and that they may have belonged to lime-secreting nullipores or algæ. Dr. J. Kinahan found marks on the rocks of Bray Head like the mounds and holes of lob-worms, and was led thereby to the discovery of the casts of the tubes below, and by a lucky blow disclosed one which retained what he believed to be marks made by the tentacles, a reduced sketch of which is shown above, in Fig. *c*. He named the species *Histioderma Hibernicum*.

The fossil group No. 1 contains representations of all the known fossils of the Cambrian rocks yet found in Ireland. The *Oldhamia radiata* is very common in certain beds of purplish and greenish arenaceous slates in two or three places on Bray Head, and at Greystones, County Wicklow. *O. antiqua* is more rare, but has been found not only at Bray Head but at Howth by Dr. Kinahan, and was procured largely from Carrick mountain by J. Flanagan, in soft greenish slate. The *Histioderma* has not yet been found anywhere except at Bray Head, where it was discovered by Dr. Kinahan.*

Foreign Localities.

Bohemia.—The admirable researches of M. Barrande have brought to light the existence in Bohemia of a Cambrian fauna answering to that found in the Menevian group of Pembrokeshire, but apparently not yet containing representatives of the older or Harlech fauna.

Scandinavia.—In Norway a red sandstone and conglomerate lies unconformably on the older gneiss, and passes under the newer gneiss of that country, and, like the corresponding red sandstones in the north-west of Scotland, is referred to the Cambrian series.† In Sweden some horizontal shales, called "alum-schists," have yielded *Paradoxides Hickeii* and other fossils, corresponding to those of the Pembrokeshire Cambrian groups.‡

America.—In Canada the Laurentian gneiss is covered unconformably by a series of sandstones 12,000 feet thick, to which the name of "Huronian" has been given by Sir William Logan. No fossils have yet been found in it.§

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* It was figured and described by him in the *Journal Geol. Soc. Dub.* vol. viii. p. 68.

† See Geikie, *Proc. Roy. Soc. Edin.* v. p. 532. ‡ See Angelin's *Palæontologica Suecica.*

§ See Murchison, *Siluria*, p. 426, and references.

CHAPTER XXXI.

SILURIAN PERIOD.

LOWER SILURIAN.

WALES AND SHROPSHIRE.—The term Silurian is derived from the name of an old British tribe, the Silures, who inhabited part of South Wales; their borders being, for geological purposes, a little extended into Shropshire, on the one hand, and Pembroke on the other, and the district christened by Sir Roderick Murchison, Siluria. The rocks, first surveyed in that district by him, were divided into two series, an upper and a lower. These rocks, especially the lower part of the series, were afterwards found by the Geological Survey to spread to the north-west in many large undulations, so as to extend throughout North Wales also, where they were first surveyed by the Rev. Professor Sedgwick. They may conveniently be separated into two series, the Lower Silurian and the Upper Silurian; and, as before, we may take these terms for the provisional designations of the periods during which they were formed. Merionethshire and Caernarvonshire in North Wales, and Caermarthenshire in South Wales, afford us the best developed and most typical groups of the rocks formed during this period.

The groups are the following:—

	Feet.
5. Lower Llandovery rocks	1000
4. Bala beds, or Caradoc rocks	6000
3. Llandeilo flags	5000
2. Tremadoc slates	1000
1. Lingula flags	5000

The diagrammatic section given in Fig. 152 will show the relations of these groups to each other in the county of Merioneth.*

The relation of the lower part of the Silurian series to the Cambrian rocks is also shown in Fig. 150, where, however, the upper part of the former is concealed by unconformable beds belonging to the Upper Silurian series.† In all cases in North Wales, there seems to be a

* This section is condensed (by omitting the igneous rocks, and the curves and fractures which cause the same beds to be repeated over the ground) from that on Sheet 37 of the Horizontal Sections of the Geological Survey, which runs from near Harlech, across the country south of Bala Lake. It was run by Mr. Selwyn, Mr. Aveline, and myself.

† Sheet 31 of the Sections of the Geological Survey, drawn by Professor Ramsay from Menai Straits over Glyder Fawr, shows a similar relation and succession of groups.

perfect conformity between the Cambrian and the base of the lower Silurian series, and a regular gradation, so that it is difficult to fix upon

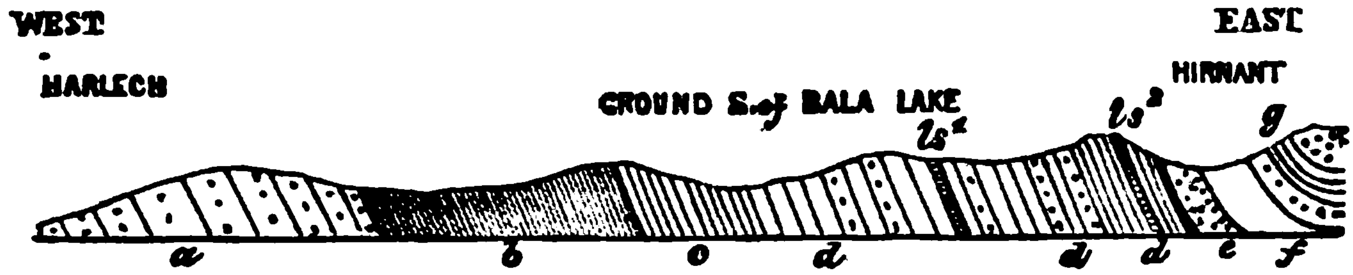


Fig. 152.

			Feet.
Base of Upper Silurian.	g.	Denbighshire sandstone (Wenlock fossils)	9500
	f.	Tarannon shales (pale slate)	500
Lower Silurian.	e.	Lower Llandovery sandstone	200
	d.	Bala beds; ls² Hirnant limestone in Bala beds; ls¹ Bala limestone in ditto	5700
	c.	Llandeilo flags	3300
	b.	Lingula flags	5000
	a.	Cambrian rocks	8000

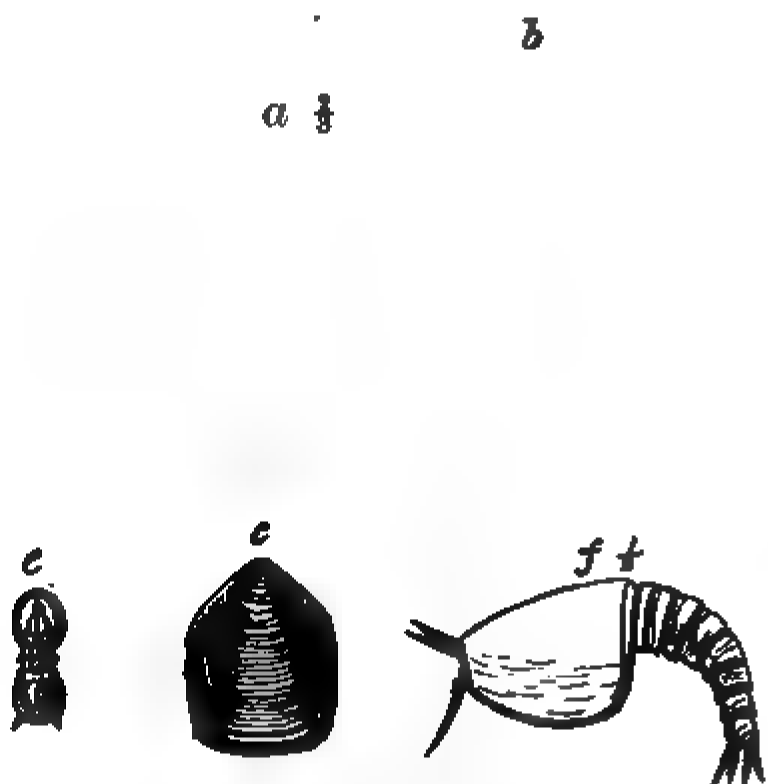
any determinate boundary between the two. This is the case even with the subdivisions of the lower Silurian rocks themselves, since the dark slates and grits or flags, of the Lingula flags, Llandeilo flags, and Bala beds, are often so similar, and graduate one into another so gently, that no good physical boundaries can be detected between the groups, and we are dependent solely on the fossils for their separation.

In South Wales the obscurity is greater on account of the lie of the rocks, which are greatly disturbed, often vertical, and traversed by numerous and rapid flexures, so that although the type of the Llandeilo flags is to be sought in Caermarthenshire, it would have been impossible there to determine the whole series. It is necessary, indeed, to trace the rocks, step by step, from Caermarthenshire into Merioneth and Caernarvon before this can be properly done, as it is also necessary to follow them from both North and South Wales into Shropshire, before their relations to the deposits of the next period can be completely understood.

1. Lingula Flags.—Immediately to the westward of the Cambrian rocks of the Longmynd in Shropshire, and therefore above them, since the dip of the rocks there is to the west, come some dark slaty shales with beds of grit and flagstone, having a thickness of 3000 or 4000 feet (see Fig. 150). In Merionethshire, in the Barmouth and Harlech country, the Cambrian rocks, rising up *en masse* about Rhinog Fawr, stretch round it with a semicircular sweep, dipping near Harlech to north-west, near Trawsfynnydd to north, and then curve round so as to dip eastward, thence down to Barmouth. They everywhere dip under, and are succeeded by, masses of dark slate, often ferruginous, with banded arenaceous flags, the surfaces of which are spotted with impres-

sions of *lingulæ*. The beds thus characterised have a thickness of about 5000 feet in this locality. In like manner, in Caernarvonshire, between the Menai Straits and the crest of the Snowdon range, the Cambrian rocks dip beneath 3000 or 4000 feet of dark blue or black slate, with grey and brown sandstone. These beds are the Lingula flags of Professor Sedgwick and Mr. Davis, a term derived from the occurrence in these strata of a *Lingulella* (formerly called *Lingula*).

The Lingula Flags pass down conformably into the top of the Cambrian series, and are indeed closely linked with that series both stratigraphically and palæontologically. Though no decided uncon-



Fossil Group No. 2.
Lingula Flag Fossils.

a. Cruziana semiplicata.
b. Dictyonema sociale.
c. Lingulella Davisii.
d. Olenus micrurus.
e. Agnostus princeps.
f. Hymenocaris vermicauda.

formability has been detected between the Lingula Flags and higher parts of the system, such is inferred to exist in North Wales, where in a distance of only eleven miles that group of strata diminishes in apparent thickness from 5000 or 6000 feet to only 2000 feet, not by an actual thinning out of the beds, but "probably by unconformable overlap." This physical break is further confirmed by a marked change in the fossils, those of the Lingula Flags differing to a great extent generically, and almost wholly specifically, from those of the overlying groups.*

* Ramsay's *North Wales—Mem. Geol. Surv.* iii. 230.

Characteristic Fossils.—About forty species of fossils have been obtained from this group. The following list may be taken as containing the characteristic forms :—

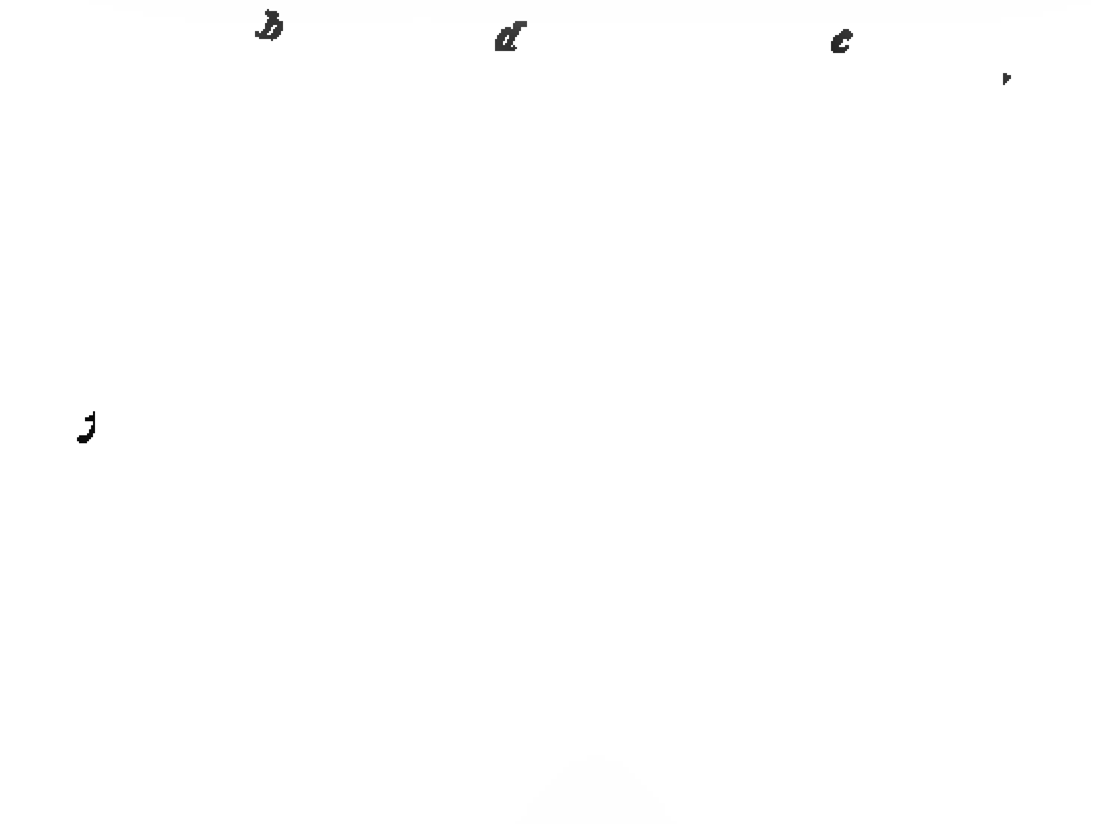
Plant . .	Cruziana semiplicata . . .	Foss. gr. 2, *a.* *
Polyzoa . .	Dictyonema sociale . . .	Foss. gr. 2, *b.*
Brachiopoda	Lingulella Davisii . . .	Foss. gr. 2, *c.*
	——— lepis . . .	M.G.S. iii. p. 334, fig. 11.
	Orthis lenticularis . . .	M.G.S., iii. pl. 4, figs. 8-10.
Crustacea .	Agnostus princeps . . .	Foss. gr. 2 *e.*
	Conocoryphe invita . . .	M.G.S., iii. pl. 4, figs. 5-7.
	——— depressa . .	Sil. foss. 5, fig. 2.
	Hymenocaris vermicauda . .	Foss. gr. 2, *f.*
	Olenus alatus.	
	——— micrurus . . .	Foss, gr. 2, *d.*
	Paradoxides Hicksii . . .	M.G.S. iii. pl. 4, fig. 12.
	——— Davidis . . .	Sil. foss. (45), fig. 1.

2. Tremadoc Slates.—Under this name is included a group of dark slates, which have only a local development, but near Tremadoc, in Caernarvonshire, attain a thickness of more than 1000 feet. Thirty-six species of fossils (on the whole, distinct from those of the Lingula Flags and the Llandeilo beds) have been obtained from these slates, including two genera of pteropods, two genera of cephalopods, seven genera of trilobites (*Angelina*, *Asaphus*, *Cheirurus*, *Conocoryphe*, *Dikelocephalus*, *Ogygia*, and *Olenus*), and the *Lingulella Davisii*. This group of strata dies out northwards, so as to allow the Llandeilo rocks to come down directly upon the Cambrian series.

3. Llandeilo Flags.—Where the whole series is most fully developed in North Wales, the Tremadoc slates are found to be covered by other beds of dark slate and sandy flags, with bands of sandstone occasionally, which cannot be separated physically from those below them, but contain a different group of fossils, and are about 5000 feet thick. In South Wales these fossils are found in a well-marked group of rocks, consisting of finely-laminated dark-brown sandy flagstones, interstratified with black earthy slates, and containing calcareous bands that sometimes become regular limestones, and are still worked for lime. Similar rocks, likewise containing one (or two) bands of limestone, occur also in North Wales, near Llanrhaidr yn Mochnant, the limestone forming, in one place, a conspicuous crag called Craig-y-Glyn. In South Wales the beds are very well seen near the small town of Llandeilo Fawr, whence Sir R. I. Murchison named them the Llandeilo flags.

* The references here given point out where figures of the fossils named may be seen. "Foss. gr." refers to the groups of fossils figured in this work; "Q. J. Geol. Soc.," to the *Quarterly Journal of the Geological Society of London*; "Sil. foss.," to the groups in the woodcuts in the 4th edition of *Siluria*; "Sil. foss. pl." to the plates in the same; "Pal. foss.," to M'Coy's *Palæozoic Fossils*, published by Professor Sedgwick; "Dec. G. S.," and "M. G. S.," to the *Decades and Memoirs of the Geological Survey*; "M'Coy, Sil. foss.," to the *Silurian Fossils* of M'Coy, published by Sir R. Griffith, Bart.; "Portl. G. R.," to Portlock's *Geological Report*. Other sources will be pointed out hereafter.

Characteristic Fossils.—These are abundant at the localities mentioned, and may frequently be procured in other places, where the group is exhibited. In a quarry by Pont Ladies, near Llandeilo Fawr, I observed, in the year 1857, some dark grey carbonaceous shales, with beds of brownish sandstone, covered with black stains, like the remains of plants. Some of these were curved linear stripes, an inch wide, and two or three feet long; others were black concretionary



Fossil Group No. 3.
Llandeilo Flag Fossils.

a. Didymograpsus Murchisonii. c. Orthis alata. e. Asaphus tyrannus.
b. Rastrites peregrinus. d. Trinucleus fimbriatus. f. Ogygia Buchii.

nodules squeezed flat in dimple-like depressions, and some stains going through the beds like roots. They were associated with small corals, and covered by beds containing the trilobite named *Ogygia Buchii*; otherwise the beds looked like Coal-measures with plant remains. They were possibly the tangled remains of sea-weeds, matted together in a bed of silt. They are interesting as giving us a possible clue to the existence of beds of anthracite, occurring either in these rocks or the next succeeding group.

*Actinozoa** .	Monticulipora favulosa . .	Sil. foss. 11, fig. 22.
Annelida .	Chondrites acutangulus . .	Pal. foss. pl. 1 A.

* Fossil Actinozoa are what are commonly called corals, since those without a calcareous skeleton could scarcely be preserved in any way except as very obscure marks in rocks.

Annelida .	Chondrites informis . .	Pal. foss. pl. 1 A.
	Palæochorda major . .	Pal. foss. t. 1 A.
	——— minor . .	Do. Do.
Hydrozoa .	Didymograpsus Murchisonii .	Foss. gr. 3, *a*.
	Diplograpsus pristis . .	Sil. foss. pl. 1, fig. 2.
	Graptolithus Hisingeri (sagittarius)	Q. J. Geo. Soc., viii. pl. 21, fig. 8.
	Rastrites peregrinus . .	Foss. gr. 3 *b*.
Brachiopoda	Lingula attenuata . . .	Sil. foss. 11, fig. 18.
	Orthis alata	Foss. gr. 3, *c*.
	Siphonotreta micula . .	Sil. foss. 11, fig. 17.
Conchifera.	Palæarcha amygdalis . .	M.G.S. iii. pl. 11, *b*, fig. 17.
	——— socialis . . .	M.G.S. iii. pl. 11, *a*, fig. 13.
Gasteropoda	Euomphalus Corndensis . .	Sil. foss. pl. 7, fig. 5.
	Ophileta compacta. . .	Sil. foss. 27, fig. 4.
Heteropoda	Maclurea Logani . . .	Sil. foss. 40, fig. 1.
	——— Peachii . . .	Sil. foss. 27, figs. 1, 2.
Cephalopoda	Orthoceras Avelinii . .	Sil. foss. 9, fig. 4.
Annelida .	Nereites Cambrensis . .	Sil. foss. 42, fig. 3.
	——— Sedgwickii . .	Sil. foss. 42, fig. 2.
Crustacea .	Æglina binodosa . . .	Sil. foss. 9, fig. 6.
	Ampyx nudus . . .	Sil. foss. 48, fig. 7.
	Asaphus laticostatus . .	Pal. foss. p. 170.
	——— tyrannus . . .	Foss. gr. 3, *e*.
	Calymene parvifrons . .	Sil. foss. 10, fig. 4.
	Illænus perovalis . . .	Sil. foss. 4, figs. 13, 14.
	Ogygia Buchii . . .	Foss. gr. 3, *f*.
	——— Selwynii . . .	Sil. foss. 9, fig. 8.
	Trinucleus fimbriatus . .	Foss. gr. 3, *d*.
	——— Lloydii. . .	Sil. foss. 10, fig. 7.
	? Ribeiria complanata . .	Sil. foss. 8, and p. 521.

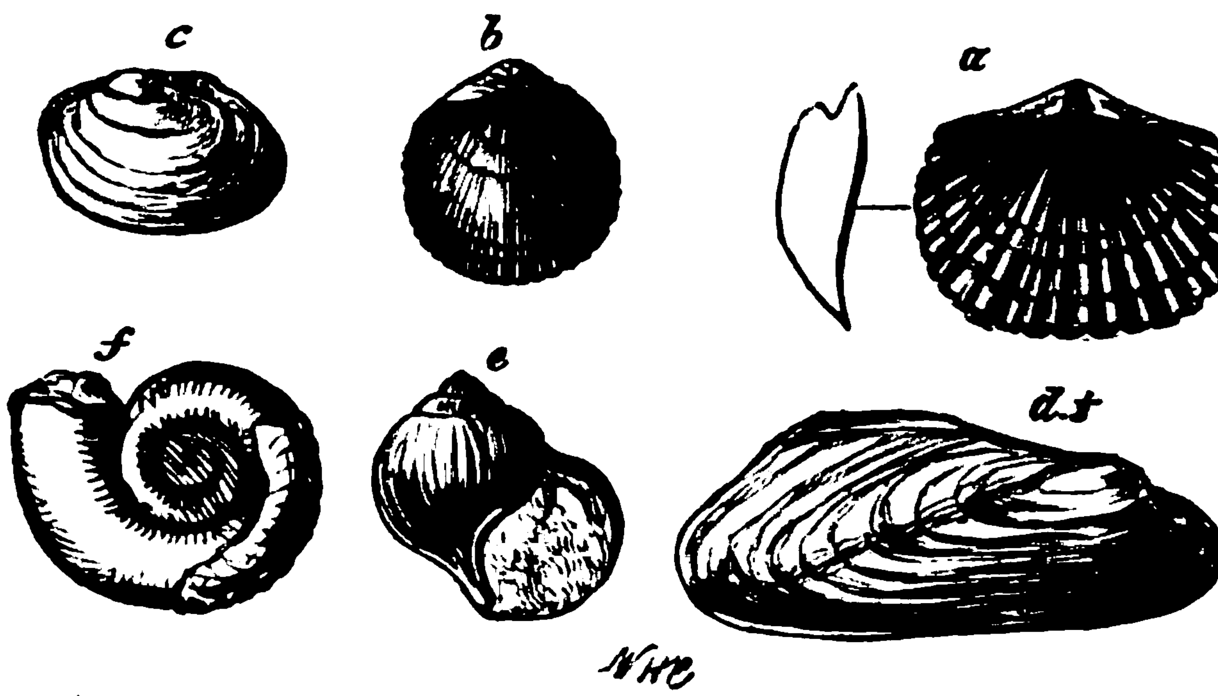
4. **Bala and Caradoc Group.**—The central part of Merioneth, around the town of Bala and its lake, affords the most typical example of these rocks. No hard line, however, can be drawn between them and the Llandeilo flags below. The black slates gradually become more sandy and gritty in texture, and more grey in colour, as we pass from the Arenig mountains towards Bala, so that over the black slates which we may assign to the Llandeilo flags, we get grey grits and slates with a total thickness of 5000 or 6000 feet, which we may class with the Bala beds. This thickness may be subdivided near Bala in the following way :—*

	Feet.
g. Dark grey and black sandy slates . . .	1200
f. Hirnant limestone	10
e. Grey sandy slates and grits . . .	1500
d. Bala limestone	25
c. Grey sandy slates and grits . . .	1400
b. Bala "ash bed" or tuff	15
a. Grey sandy slates and sandstones . .	(say) 1350
	5500

* See section, Fig. 152.

The Bala tuff (*b*) disappears in the hills to the south of the lake, although the calcareous band (*d*) called the Bala limestone is distinctly traceable some miles farther south, dying away towards Dinas Mowddwy. The Hirnant limestone (*f*) is only seen at one spot in the valley called Hirnant, three miles east of Bala, and another a mile or two north of it. As the beds are traced to the northwest and west, the Bala limestone retains its characters very persistently to the neighbourhood of Penmachno, and the tuff (*b*) is always found at about the same distance below it ; another similar tuff coming in, in some places, about a thousand feet lower down. The occurrence of the two peculiar beds, the limestone and the tuff, below it, enabled me, when surveying the ground in 1846 and 1847, to trace them through a number of large dislocations across a broken country, from the valley of the Dee to that of the Conway.

To the west of the Conway valley the Bala beds became more and more invaded by igneous rocks, both contemporaneous and intrusive, and the tuffs or ash-beds join on to their parent bands of contemporaneous trap. The grey gritty



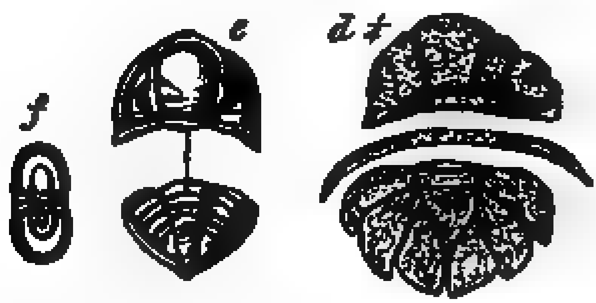
Fossil Group No. 4.
Bala and Caradoc Fossils.

a. Orthis flabellulum.
b. Orthis elegantula.
c. Ctenodonta semitruncata.
d. Modiolopsis expansa.
e. Holopea concinna.
f. Lituites Hibernicus.

slates become more purely black slate as we approach the town of Conway, though thick beds of brownish sandstone occur in them. Some of these sandstones are calcareous, and probably are on the same horizon as the Bala limestone, and they have below them two thick masses of felstone trap, separated by slate, which contains a peculiar bed of purple conglomerate ; these felstones being, perhaps, the old submarine flows from which the ash-beds of the Bala country derived their origin. This peculiar succession again made it possible to trace a series of faults with throws of two or three thousand feet across the hills south of Conway.

Farther south a great calcareous tuff, forming the upper part of Snowdon, is considered by Professor Ramsay to be the representative of the Bala limestone ; and enormous masses of igneous rocks spread below it with such complication as to have required years of labour on the part of my colleagues, Ramsay, Selwyn, and Aveline, to disentangle and lay them down on the published maps and sections of the Geological Survey. For not only were these great masses of igneous rocks of almost all varieties, and both of contemporaneous and intrusive

character, but similar igneous masses occur on different geological horizons. The traps of Snowdonia, for instance, which lie in the Bala beds, die away towards the south-east into one or two thin tuffs, and gradually disappear altogether, while a similar series commences in that direction in the Llandeilo and Lingula flags, forming the hills known as the Arenigs, Aran Mowddwy, and Cader Idris. A corresponding change takes place simultaneously in the aqueous rocks, the Bala beds of Caernarvonshire more nearly resembling some of the Llandeilo beds of Merioneth than they do those of the proper Bala country. This changing series is, moreover, thrown into many abrupt curvatures over parallel anticlinal and synclinal axes, the radii of the curves being often some miles in length, while numerous and very large* dislocations traverse the rocks in almost every direction, leaving them, in some parts, like a heap of disjointed ruins. The ruins, too, have been worn and gullied by denuding agencies, and are only to be examined here and there where they are uncovered by soil or vegetable growth. The



Fossil Group No. 5.
Bala and Caradoc Fossils.

a. Echinosphærites aurantium.	d. Lichas Hibernicus.
b. Sphæronites Litchi.	e. Phacops apiculatus.
c. Illænus Davisii.	f. Agnostus trinodus.

difficulty of the task of determining the former order and arrangement of their several parts can only be appreciated by those who go over the ground with the geological maps and sections in their hands, and verify our interpretation of its structure.

If from the typical Bala county we proceed eastwards towards Shropshire, the Bala beds assume another phase. They lose most of their igneous rocks, and much of their slaty character, and pass into a formation of brown sandstone, with occasional calcareous bands, in which form they were first described by Sir R. I.

* One magnificent dislocation runs for nearly sixty-six miles from the lowland of Cheshire, through the Hundred of Yale in Denbighshire, down through Bala Lake, on the west side of Arran and east of Cader Idris, through Tal-y-llyn to the sea coast near Towyn. It dislocates the Carboniferous as well as the Lower Silurian rocks, and has an apparent downthrow to the north-west of 3000 or 4000 feet. It might be well called the Yale and Bala fault.

Murchison under the name of the Caradoc Sandstone. This name is derived from the hill called Caer Caradoc, near Church Stretton, the ancient caer or camp on which is named after the old British King, Caradoc,* whom the Romans called Caractacus. †

Characteristic Fossils.—In the identification of a formation thus varying in lithological type, it is obvious that great assistance must be derived from its everywhere containing certain characteristic fossils, of which the following is a list of the most remarkable and abundant species :—

Hydrozoa . .	Didymograpsus caduceus .	Q. J. Geol. Soc., ix. p. 87.
	Diplograpsus bullatus . .	Q. J. Geol. Soc., vii. p. 174.
	Graptolithus Conybeari . .	Q. J. Geol. Soc., viii. p. 390.
Polyzoa . .	Ptilodictya acuta . . .	Sil. foss. 27.
	? Dictyonema (Fenestella) capillaris	Portl. Geol. Report, p. 323.
Echinodermata	Agelacrinus Buchianus . .	Sil. foss. 33, fig. 6.
	Echinosphærites aurantium .	Foss. gr. 5, *a*.
	———— Balticus .	Sil. foss. 33, fig. 1.
	Palæaster asperrimus . .	Sil. foss. 34, fig. 2.
	——— obtusus . . .	Sil. foss. 34, fig. 1.
	Spheronites Litchi. . .	Foss. gr. 5, *b*.
Annelida . .	Crossopodia Scotica . .	Sil. foss. 42, fig. 4.
	Trachyderma læve. . .	M'Coy. Pal. foss., p. 133.
Crustacea . .	Acidaspis Jamesii . . .	Dec. 7, t. b.
	Æglina mirabilis . . .	Sil. foss. 29, Fig. 3.
	Agnostus trinodus . . .	Foss. gr. 5, *f*.
	Asaphus Powisii (*and Llandeilo*)	Sil. foss. 46, Fig. 1.
	Beyrichia complicata *Do.*	Sil. foss. 11, Fig. 10 *a*.
	Calymene brevicapitata *Do.*	Sil. foss. 11, Fig. 9.
	Cheirurus clavifrons . .	Sil. foss. 48, Fig. 1.
	Harpes Flanagani . . .	Sil. foss. 48, Fig. 4.
	Illænus Bowmanni *Do.*	Dec. G. S., No. 2.
	Illænus Davisii . . .	Foss. gr. 5, *c*.
	Lichas Hibernicus . . .	Foss. gr. 5, *d*.
	Phacops apiculatus *Do.*	Foss. gr. 5, *e*.
	Remopleurides dorso-spinifer .	Sil. foss. 48, Fig. 5.
	Staurocephalus globiceps .	Port. Geol. Rep., p. 257.
	Trinucleus seticornis . .	Sil. foss. 14, Fig. 2.
Brachiopoda .	Discina (Orbicula) punctata .	Sil. foss. 35, fig. 1.
	Orthis elegantula . . .	Foss. gr. 4, *b*.
	—— flabellulum . . .	Foss. gr. 4, *a*.
	—— insularis (galeas) . .	M'Coy, Sil. foss. pl. 3, fig. 12.
	—— vespertilio . . .	Sil. foss. 13, fig. 7.
	Strophomena complanata .	Sil. syst., p. 636.
Conchifera .	Ctenodonta semitruncata .	Foss. gr. 4, *c*.
	Modiolopsis expansa . .	Foss. gr. 4, *d*.
	Orthonota nasuta . . .	Sil. foss. 13, fig. 12.

* In the pronunciation of Welsh words the accent is always to be thrown on the penultimate syllable, so that although in Shropshire the name is pronounced Cáradoc, in Wales it would be called Carádoc.

† The student should consult on this formation the memoir by Professor Ramsay on North Wales, *Mem. Geol. Survey*, vol. iii.

Gasteropoda .	Cyclonema rupestris . .	Sil. foss. 40, fig. 4.
	Holopæa concinna . . .	Foss. gr. 4, fig. *e*.
	Raphistoma equale . .	Sil. foss. 40, fig. 2.
Heteropoda .	Bellerophon nodosus . .	Sil. foss. 13, fig. 11.
Cephalopoda .	Lituites Hibernicus . .	Foss. gr. 4, *f*.
	Orthoceras vagans . . .	Sil. foss. 42, fig. 1.
	Poterioceras approximatum .	M'Coy, Sil. foss., p. 10.

5. Lower Llandovery Rocks.—In tracing the top of the Bala beds from North Wales into South Wales, certain beds of sandstone come in. In the neighbourhood of the little town of Llandovery, in Caermarthenshire, a bed of conglomerate occurs which may be taken as the base of a series of sandstones and shales, varying from 200 to 900 feet in thickness, which appear to belong physically to the Bala beds ; and to be a mere local subdivision of that series. There is, however, rather a peculiar assemblage of fossils in them, 11 species being confined to the group, 93 ranging into it from the Bala beds below, and 83 passing from it into the Upper Llandovery group. Some of the fossils peculiar to the group, and therefore characteristic of it, are—

Nidulites favus	Sil. foss. 27.
Meristella crassa	Sil. foss. pl. 9.
——— angustifrons	Foss. gr. 6, *b*.
Murchisonia angulata	Sil. foss. pl. 10, fig. 12.
Holopella tenuicincta	M'Coy, Pal. foss. 304.

Some of those which range from the Bala beds below into the Lower Llandovery rocks, are the following :—*

Petraia subduplicata	Sil. foss. 14.
Orthis Actoniæ	Sil. foss. 32.
Orthis caligramma.	Sil. foss. 9.
Murchisonia simplex	M'Coy, Pal. foss. 294.
Homalonotus bisulcatus	Sil. foss. 9.
Illænus Bowmanni	Dec. G. S. 2.
Lichas laxatus	Sil. foss. 44.

The group is connected with the rocks above by the occurrence of *Pentameri*, especially *Stricklandinia* (*Pentamerus*) *lens* (Foss. gr. No. 6, Fig. *d*), in great abundance (whence the two groups of Llandovery rocks are sometimes called the Pentamerus beds), and by the following fossils :—

Petraia bina	Sil. foss. 52.
Atrypa hemispherica and marginalis . .	Sil. foss. pl. 9.
Leptæna scissa and transversalis . . .	Sil. foss. pl. 9.
Phacops Stokesii	Sil. foss. pl. 10, fig. 6.
Pterinea retroflexa.	Sil. foss. pl. 9, fig. 26.

besides several that range from the Lower into the Upper Silurian groups.

* Consult Murchison's *Siluria*, chaps. iv. and ix. ; Ramsay, *op. cit.* pp. 230-3 ; Hor. Sect. Geol. Survey, Sheet 4 ; and *Quart. Journ. Geol. Soc.*, vol. xix. (President's Address).

It is probable that this group of rocks has in reality a much wider extension than has yet been assigned to it, and that it occupies more or less of the large tract of Lower Silurian ground which spreads in numerous undulations through Cardiganshire and the adjacent counties. The Plynlymmon group of Professor Sedgwick, in part at least, belongs to it, as appears from the list of fossils got at the Devil's Bridge, and determined by Mr. Salter, in which *Atrypa crassa* occurs.* Professor Sedgwick's Aberystwith group may possibly, perhaps, belong to the Bala beds below; but the whole country is so violently contorted, and thrown into such numerous and rapid undulations, that it is almost impossible to observe directly the order of superposition of the rocks, as appears from the fact of Professor Sedgwick's placing his groups below the Llandeilo flags instead of above them, which from Professor Ramsay's section † is obviously their true position.

CUMBERLAND AND WESTMORELAND.—In these counties the lower Llandeilo flags are represented by a thick group of slates, known as the Skiddaw slates, containing graptolites, trilobites, and brachiopods of Llandeilo types, but the Lingula flags are nowhere reached. Above the Skiddaw group comes a great succession of green slates and porphyries—derived from the ejections of Lower Silurian volcanoes. In these beds fossils are very rare, but overlying them comes the Coniston limestone, which, from its fossils, is identified with the Bala limestone. These rocks pass under other beds which represent the upper division of the Silurian system.‡

SCOTLAND.—The southern uplands of Scotland consist almost wholly of Lower Silurian rocks, forming a long continuous strip of high ground from St. Abb's Head to Portpatrick. The greater part of this area appears to belong to rocks of Llandeilo age; here and there, particularly in Ayrshire and at the Leadhills, portions of a Caradoc or Bala series appear, while in the former area these are overlaid with Lower Llandovery rocks. In the Llandeilo series graptolites are the chief fossils, being particularly abundant in certain dark anthracite shales which occur in different horizons, as at Moffat and Leadhills. The Caradoc limestones of Ayrshire have yielded a large assemblage of corals, brachiopods, trilobites, etc.§

The Scottish Highlands, as shown by the labours of Sir Roderick Murchison, consist almost wholly of metamorphosed Silurian rocks. From underneath the thick formations of gneiss and schist forming the great mass of these districts, there rise in the west of Sutherland and

* See *Quart. Journ. Geol. Soc.*, vol. iii. p. 152.

† Horiz. Sect. Geol. Survey, Sheet 4.

‡ *Siluria*, p. 146, and papers by Professor Harkness (*Quart. Journ. Geol. Soc.*, vols. xix. xi. and xxiv.), and by him and Dr. Nicholson, *op. cit.* vol. xxii. pp. 480-8.

§ See Murchison's *Siluria*, pp. 148-58, and references there cited; Geikie, "On the Succession of the Silurian Rocks of Scotland," *Trans. Geol. Soc. Glasgow*, vol. iii.

Ross quartz-rocks and limestones in which orthoceratites and other recognisable Lower Silurian fossils occur. The subsequent conjoint researches of Sir Roderick and Mr. Geikie have made it clear that the lower or quartz-rock series, with associated limestones, is brought up again and again by vast folds of the strata spreading over the Highlands, up to their southern border.*

IRELAND.—The Lingula flags are not yet known in Ireland. Their discovery would be of interest, as throwing light on the question whether they would be conformable to the Cambrian or to the Lower Silurian rocks, or would, as in Wales, introduce conformity throughout the series. The Lower Silurian rocks of Wicklow, Wexford, and Waterford, are of the Bala and Caradoc age, as shown by their fossils, and have unfossiliferous beds below them, which may or may not belong to the Llandeilo group. They rest unconformably on the Cambrian rocks below, and consist of dark-blue or black, and grey flags, slates, and grits, sometimes, as in Wales, becoming purple, green, olive, etc. They contain many beds of contemporaneous volcanic rocks (felstone, tuff, etc.) like those of Wales, and one or two calcareous bands (very like the Bala limestone) near Courtown, and at Tramore. Their thickness must be many thousand feet, but there are no good continuous sections sufficient to determine it exactly. The fossils are found only in the upper part of the series, in the neighbourhood of the igneous rocks† and calcareous bands, and the exact relations of the lower beds are accordingly unknown. The island of Lambay, and the promontory of Portraine in County Dublin, also expose slates and calcareous bands belonging to this period, and full of characteristic Bala fossils, as do also the hills of the Chair of Kildare.‡

Another great tract of apparently similar beds stretches from the centre of Ireland (Cavan, etc.), to the coast of Down. Among these, however, a portion certainly belongs to the Llandeilo flags, as near Bellewstown, on the confines of Dublin and Meath, an assemblage of the following fossils characteristic of that group was collected years ago by the late J. Flanagan, and determined by Mr. W. H. Baily, viz.—*Didymograpsus Murchisonii*, *Diplograpsus pristis*, *Graptolithus Nilsoni*, *G. sagittarius*, *Siphonotreta micula*, *Lingula* resembling *L. ovata*.§ At a place called Kilnaleck, in the County Cavan, a band of anthracite occurs in these rocks, and may be traced also in County Down, as if

* See the authorities cited in the footnote, *ante*, p. 524.

† The eruption of igneous rocks at the bottom of the sea, though doubtless occasionally destructive of animal life at the moment, seems generally favourable to its development during the period. Contemporaneous trap-rocks have often highly fossiliferous beds intimately associated with them.

‡ See Explanation of Sheets 102, 112, and 119 of the Maps of the Geological Survey of Ireland.

§ See Baily, *Journ. Geol. Soc. Dublin*, ix. p. 300.

striking from the similar anthracitic bands of the south of Scotland. It is associated with black slates containing an assemblage of graptolites, resembling those of the Scottish beds. On Slieve Bernagh, in the County Clare, north-west of Killaloe, first examined by Mr. G. H. Kinahan, graptolite shales are again found, containing several Llandeilo species. Beds believed to be of the same age form the heart of the Galty mountains. In the Cratloe hills, north of Limerick, rocks occur which probably belong to the Lower Llandovery group, while at one place there, fossils of Upper Llandovery age have been obtained. The rocks of the hill called Knockshigowna also, to the west of Roscrea, are probably of Llandovery age. In the north of Ireland the Lower Silurian rocks of Pomeroy, Tyrone, and other places, yielded a rich harvest of fossils to the labours of the geological branch of the Ordnance Survey under the late General Portlock.*

On the flanks of the Dublin and Wicklow granites, the Lower Silurian slates and grits are greatly metamorphosed into mica and other schists, and occasionally into gneiss, and are often full of crystals of andalusite, staurolite, schorl, felspar, and other minerals. Other metamorphic tracts in the north-west of Ireland may be also composed of metamorphosed Lower Silurian rocks.†

Foreign Localities.

Bohemia.—By the long and laborious researches of M. Barrande the general palæontological succession among the Silurian rocks of Bohemia has been well made out. That observer divides the strata of the Silurian basin of that country into stages (étages), each characterised by a distinctive fauna, and marked by him with a distinguishing letter. His Stage C, or primordial zone, corresponds to our Lingula flags. It consists of argillaceous schists, and contains what Barrande calls his Primordial fauna. Its trilobites belong to the genera *Agnostus*, *Arionellus*, *Conocephalus*, *Ellipsocephalus*, *Hydrocephalus*, *Paradoxides*, and *Sao*—genera which, except *Agnostus*, are entirely confined to that zone. Stage D corresponds to our Bala or Caradoc group, so that the Llandeilo group seems to be either unrepresented in Bohemia or to be divided between Stages C and D. The latter stage consists of quartzites, etc., and includes the second fauna of Barrande, which contains 81 species of trilobites belonging to the genera *Acidaspis*, *Æglina*, *Ampyx*, *Asaphus*, *Cheirurus*, *Illænus*, *Ogygia*, *Trinucleus*, and 22 others.

Scandinavia.—In the northern parts of Norway the order of succession among the older palæozoic rocks appears closely to resemble that of Scotland. An older or bottom gneiss, probably Laurentian, is unconformably overlaid by red sandstones (Cambrian) over which comes an upper metamorphic series with rare fossils, and believed to be of Lower Silurian age. In Southern Norway and in Sweden the Silurian rocks are comparatively undisturbed and unaltered. They are there never much more than 1200 feet thick, and are yet said to contain representatives of each of the groups which make up the 30,000 feet of British Silurian strata.‡

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* See his *Report on the Geology of Londonderry*, etc.

† See Harkness, *Quart. Journ. Geol. Soc.* xvii. 256; and xxii. 506.

‡ Murchison, *Siluria*, p. 354.

In Sweden M. Angelin has examined the rich fauna of these rocks, and divides the Silurian system there into regions, according to the characteristic fossils. His Region A (*Olenorum*) and Region B (*Conocorypharum*), consisting of aluminous schists and limestone, are approximately equal to Stage C of Barrande, and therefore to our Lingula flags. The Scandinavian strata contain 71 species of trilobites of the same peculiar genera as the Bohemian beds, but without one identical species. Angelin's Regions B C (*Ceratopygarum*) consisting of aluminous schist and black limestone; C (*Asaphorum*) formed of grey and reddish impure limestones; and D (*Trinucleorum*), consisting of marly schists with calcareous concretions, are together approximately equal to Stage D of Barrande. There are 81 species of trilobites in the Bohemian beds D, and 176 in those of Scandinavia, B C, C, and D. The genera are the same in both countries, and the species nearly allied; but there is said to be not one species common to the two districts.* It is yet doubtful whether these specific differences, existing together with generic identities, be due to a want of exact synchronism in the age of the beds, or to the geographical distribution and limitation of the life of the period; whether, in fact, they are the result of time or space.

North America.—A copious development of the Lower Silurian system has been found to spread over wide tracts of the United States and Canada. The subjoined table shows the subdivisions there established, with some of their characteristic fossils.

TABLE OF THE LOWER SILURIAN SYSTEM OF NEW YORK AND CANADA.†

Lower Llandovery Rocks.	Medina Sandstone	*Lingula Cuneata*, *Atrypa plicata*, *A. reticularis*, *Pentamerus Barrandi*, *Modiolopsis proprigenia*, *Calymene Blumenbachii*.
	Oneida Conglomerate	*Corals*; *Leptæna sericea*, *L. transversalis*, *Strophomena alternata*, *S. depressa*; *Pentamerus reversus*, *Bellerophon bilobatus*, *Calymene Blumenbachii*.
Caradoc Beds	Hudson River Beds	Fossils in great part the same as in Trenton Limestone. *Tentaculites*; *Orthis testudinaria*; *Strophomena alternata*; *Leptæna sericea*; *Bellerophon bilobatus*; *Ambonychia radiata*; *Modiolopsis modiolaris*; *Trinucleus concentricus*, etc.
	Utica slate	*Graptolites*, *Lingula*, *Orbicula*, *Orthis*; trilobites chiefly the same as in group above.
	Trenton and Bird's-eye Limestones	Crinoids abundant; cystideans; starfish; *Chætetes*; *Lingula*; *Leptæna*; *Strophomena*; *Atrypa* (many species); *Avicula*; *Pleurotomaria*; *Holopæa*; *Murchisonia*; *Bellerophon*; *Asaphus*; *Isoteles*; *Illænus*; *Phacops*; *Calymene*; *Aciduspis*; *Trinucleus*; many *Cephalopoda*.

* Barrande's *Parallèle entre les depôts Siluriens de Bohême et Scandinavie.*

† From *Siluria*, p. 446.

TABLE OF THE LOWER SILURIAN SYSTEM OF NEW YORK AND CANADA—*continued.*

Llandeilo Beds.	Chazy, Sillery, Lanzon, and Lévis Limestones } Quebec Group.	Fossils as a whole much the same as in Trenton limestone.
	Upper Calciferous Sandrock	*Murchisonia* and *Pleurotomaria* (several species).
Tremadoc Slates.	Lower Calciferous Sandrock; Upper Potsdam Sandstone	Polyzoa and Corals; Encrinites; *Leptæna, Orthis, Atrypa; Maclurea magna; Raphistoma, Murchisonia; Illænus, Isoteles.*
Lingula Flags.	Lower Potsdam Sandstone; St. John's Group	*Ophileta compacta, Maclurea, Turbo, Orthoceras, Lingula prima* and *L. antiqua, Scolithus; Cruziana* and Sea-weeds.
Cambrian .	Huronian	No fossils yet found in America.

UPPER SILURIAN.

If we return to the neighbourhood of Llandovery, in South Wales, we shall find that over the sandstones already described as the Lower Llandovery beds, certain other sandstones come in, not very different from them in lithological character, and having some fossils in common with them. They vary there from 300 to 700 feet thick. They are separated from the Lower Llandovery, because they rest unconformably upon them and overlap them, so that when traced towards the north they rest directly on the Bala beds.* They are called the Upper Llandovery rocks, and they form the true base of the Upper Silurian series. That they are physically distinct from the Lower Llandovery is shown not only by the local unconformity near Llandovery, where they are both present, but also by the fact that wherever the Lower Llandovery rocks are to be seen they adhere to and form the top of the Lower Silurian series, while, wherever the Upper Llandovery are seen, they lie conformably beneath the rest of the Upper Silurian series, but are distinctly and often widely unconformable to the Lower Silurian. It is indeed a remarkable fact that wherever the Upper Silurian and Lower Silurian rocks are found together in anything but a horizontal position, there is an unconformable break between them. This is often a clear discordance in the lie of the rocks, so that they obviously dip in different directions or at different angles. But even where there is no apparent unconformability, and they dip and strike apparently together, the unconformity may eventually be discovered by different parts of the two series being in apposition in different places.

It has sometimes been proposed to join the Lower and Upper Llandovery rocks as a separate or Middle Zone of the Silurian system. The fossils of these two groups have a common general *facies* sufficient to

* See Geological Survey Maps, Sheets 41 and 42; and Horizontal Sections, Sheet 4.

mark them off from the other Silurian formations, but hardly such as to warrant the erection of a middle division of the system. They are undoubtedly beds of passage between Lower and Upper Silurian strata. The physical break or unconformability between the Lower and Upper Llandovery rocks of Wales has served as a convenient, though somewhat arbitrary line of division between Lower and Upper Silurian. But though this physical discontinuity is accompanied also by a change in the fossils, the two great sections of the Silurian system are connected with each other organically by the species which pass from the Caradoc into the Upper Llandovery beds.

The typical subdivisions of the Upper Silurian series of Wales and the adjacent parts of England are the following:—

		Feet.
	9. Tilestone	1000
Ludlow group	8. Upper Ludlow rock	900
	7. Aymestry limestone	150
	6. Lower Ludlow rock	900
Wenlock group	5. Wenlock limestone	150
	4. Wenlock shale	1400
	3. Woolhope limestone	50
Llandovery or May Hill group	2. Tarannon shale	600
	1. Upper Llandovery rocks	900

A section taken across Wenlock Edge (Fig. 153) or in the Woolhope Valley, Herefordshire, shows the way in which these groups of

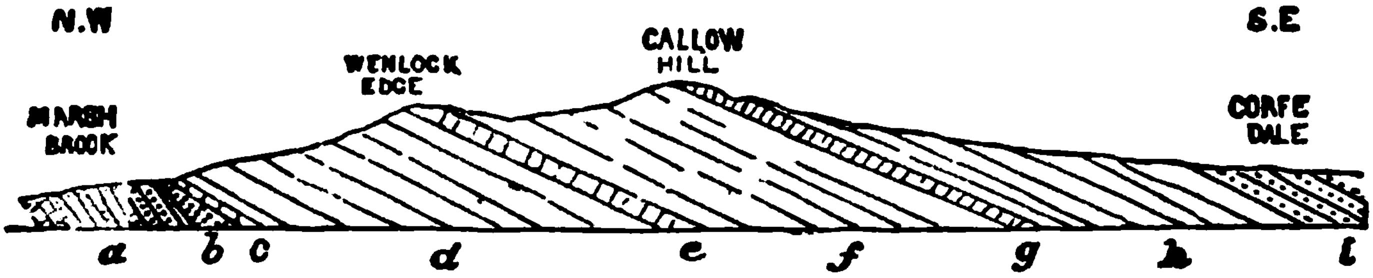


Fig. 153.

Section across Wenlock Edge, reduced from Sheet 34 of Horizontal Sections, Geological Survey. Drawn by W. T. Aveline.

Length of Section about four miles.

		i. Red Sandstone, supposed base of Old Red Sandstone.	
Upper Silurian.	Ludlow rocks.	*h.* Upper Ludlow—Grey and brown shale and sandstone	900 feet.
		g. Concretionary limestone (Aymestry)	150 ,,
		f. Lower Ludlow—Grey and brown calcareous sandy shale	900 ,,
	Wenlock rocks.	*e.* Grey nodular concretionary limestone (Wenlock and Dudley limestone)	150 ,,
		d. Grey and brown sandy shale, often concretionary (Wenlock shale)	1400 ,,
		c. Limestone (Woolhope and Barr)	50 ,,
	Llandovery	*b.* Sandstone and Conglomerate (Llandovery).	
Lower Silurian		*a.* Bala beds or Caradoc Sandstone.	

rock succeeded each other between the Lower Silurian rocks on which they rest, and the Old Red Sandstone which overlies them.

Upper Llandovery Group.—In parts of Shropshire the unconformity between Lower and Upper Silurian rocks is not very striking, and it so happens that there the Bala and Caradoc beds consist of yellow and brown sandstones of very much the same character as the Llandovery beds which overlie them, so that they were originally classed together under the name of the Caradoc sandstone. They had in like manner been called Caradoc on the west flank of Malvern, at Woolhope, and May Hill, and elsewhere. Professor Sedgwick was the first to point out the necessity for separating these beds from the Lower

Fossil Group No. 6.
Llandovery Fossils.

a. Atrypa hemispherica.
b. Meristella angustifrons.
c. Orthis reversa.
d. Stricklandinia lens.
e. Pentamerus oblongus.
f. Chiton Griffithii.
g. Cyrtoceras approximatum.

Silurian, and proposed the name of the May Hill Sandstone for them.* Messrs. Aveline and Salter afterwards traced the unconformity between them and the Caradoc beds in Shropshire,† and their presence was subsequently recognised as the base of the Upper Silurian series in many other localities. After several names, such as Upper Caradoc, Pentamerus beds, Wenlock grit, etc., had been proposed and discarded, they now seem to have been settled as Llandovery rocks. To this, however, the name "May Hill Sandstone" should be added as a second title,

* *Quart. Journ. Geol. Soc.*, ix. 215. † *Op. cit.* x. 62.

since Professor Sedgwick, with M'Coy, first indicated their distinctness, although they did not work it so thoroughly out as was afterwards done by the Geological Survey.

1. **The Upper Llandovery or May Hill Sandstone** is usually a grey, or brown, or yellow sandstone, sometimes becoming a conglomerate. The sandstones are sometimes calcareous, passing into courses of sandy limestone in some places. Of about 230 species of fossils found in this subdivision, the following may be said to be characteristic of this group :—*

Actinozoa .	Cyathophyllum angustum .	Sil. foss. pl. 39.
	Petraia bina (*and Wenlock*)	Sil. foss. pl. 38.
	——— elongata . . .	Sil. foss. pl. 38.
Brachiopoda .	Atrypa hemisphærica . .	Foss. gr. 6, *a*.
	——— reticularis . .	Sil. foss. pl. 9.
	Lingula crumena . .	Sil. foss. 12.
	——— parallela . .	Mem. G. S. ii. pt. I.
	Orthis lata. . . .	Sil. foss. pl. 9.
	——— reversa . . .	Foss. gr. 6, *c*.
	Pentamerus globosus . .	Sil. foss. pl. 8.
	——— oblongus . .	Foss. gr. 6, *e*.
	——— undatus . .	Sil. foss. 14.
	Stricklandinia (Pentamerus) lens	Sil. foss. pl. 8.
	——— ——— lirata	Sil. foss. 15.
	Meristella (Rhynchonella) angustifrons . . .	Foss. gr. 6, *b*.
	Rhynchonella neglecta .	Sil. foss. 9.
	Strophomena compressa .	Sil. foss. pl. 9.
Conchifera .	Pleurorhynchus pristis .	M'Coy, Sil. foss.
	Ctenodonta deltoidea . .	Mem. G. S. ii. p. 366.
	——— Eastnori . .	Sil. foss. pl. 10.
	——— lingualis . .	Mem. G. S. ii. p. 367.
	Lyrodesma cuneata . .	Mem. G. S. ii. p. 366.
	Pterinea sublævis . .	M'Coy, Sil. foss. p. 23.
	——— bullata . .	M'Coy, Sil. foss. p. 23.
Gasteropoda .	Chiton Griffithii. . .	Foss. gr. 6, *f*.
	Cyclonema quadristriata .	Mem. G. S. ii. p. 388.
	Euomphalus prænuntius .	Mem. G. S. ii. p. 357.
	Holopella plana . . .	M'Coy, Sil. foss. p. 12.
	——— tenuicincta . .	M'Coy, Pal. foss. p. 304.
	Macrocheilus fusiformis .	Sil. foss. pl. 10.
	Murchisonia angulata . .	*Ibid.*
	Pleurotomaria fissicarina .	Mem. G. S. ii. p. 357.
	Raphistoma lenticularis .	Sil. foss. pl. 10.
	Trochonema tricincta . .	M'Coy, Sil. foss. p. 14.
	Trochus ? multitorquatus .	*Ibid.* p. 15.
	Turbo ? tritorquatus . .	*Ibid.* p. 12.
Cephalopoda .	Cyrtoceras approximatum .	Foss. gr. 6, *g*.
	Lituites undosus . .	Sil. foss. pl. 11.
	Orthoceras Barrandii . .	Q. J. Geol. S. vii. p. 177.
	Tretoceras bisiphonatum .	Sil. foss. pl. 11.

* Catalogue in the last edition of *Siluria*.

Echinodermata	Palæaster coronella . .	Ann. Nat. Hist. s. 2, xx. p. 326.
	Palæchinus ? Phillipsiæ .	M. G. S. ii. p. 584.
	Pleurocystites Rugeri . .	M. G. S. iii. p. 223.
Crustacea . .	Acidaspis callipareos . .	Q. J. G. S. xiii. p. 308.
	Encrinurus punctatus . .	Sil. foss. pl. 10.

2. The Tarannon Shales.—In the Llandovery country the Upper Llandovery or May Hill rocks are succeeded by a group of pale grey, smooth, fine-grained slate rocks, to which the name of "Tarannon shales" has been given by Professor Ramsay, from the valley and river of that name, between Llanidloes and Dinas Mowddwy, where they attain a thickness of 600 feet. These pale slates sometimes change into a bright red. They may be traced from South Wales into North Wales, and followed through all the undulations of the rocks down to Conway, forming either with or without the Upper Llandovery beds a marked line of separation between the Lower and Upper Silurian districts. This little group had likewise not escaped the observation of Professor Sedgwick, who describes them under the name of the Rhayader slates, as "pale, leaden-grey, passing into greenish-grey," with "beautiful cleavage planes." He at first gave them their true place, at the lower part of the Upper Silurian, though afterwards he was led, by the wonderfully contorted condition of the country, to class them with the Lower Silurian.* Although a distinct physical group of some importance in Wales, the Tarannon shales seem to be confined to that country. Fossils are very rare in them, and it cannot therefore be said with certainty whether they belong most decidedly to the Llandovery group or to the Wenlock.

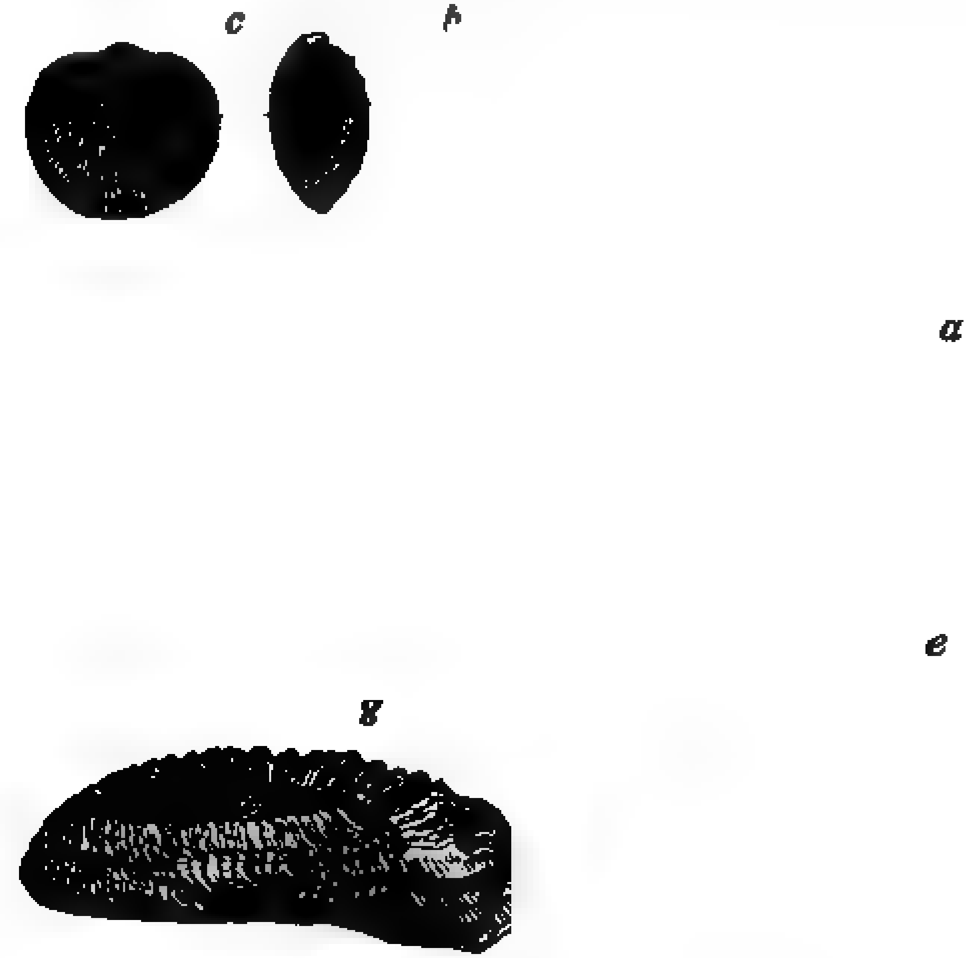
Wenlock Group.—3. Woolhope or Barr Limestone.—A locally occurring group of beds of grey, argillaceous, nodular, concretionary limestone, interstratified with grey shales, occasionally attaining a thickness of 100 feet. It forms a ring round the dome of Llandovery sandstone in the Woolhope valley, and is well seen at Nash Scar, near Presteign, on the west flanks of the Malvern hills, at Great Barr in Staffordshire, and at May Hill.

In North Wales the Tarannon shales or Rhayader slates are succeeded by a great sandstone formation, consisting of coarse brown sandstone, with occasional quartzose conglomerates, and interstratified with black slates, and passing up into brown flags and slates, which were called Denbighshire sandstone and flag by Mr. Bowman and Professor Sedgwick, a name adopted by the Geological Survey. Over these are other beds of shale or slate, and flag or sandstone. The beds which lie next above the pale Tarannon shales contain few fossils, but those are of species which show them to belong to the Wenlock group.

4. Wenlock Shale.—Generally dark grey, sometimes black shale, with occasional calcareous concretions; 1400 feet thick.

* *Quart. Journ. Geol. Soc.* iii. p. 153.

5. **The Wenlock Limestone** is an irregularly occurring set of concretionary limestones, sometimes thin and flaggy, sometimes massive bosses of highly crystalline carbonate of lime; sometimes in one, sometimes in two or three sets of beds, with interstratified shales, forming a thickness of 100 to 300 feet. These beds are admirably shown in all the country between Aymestry and Ludlow, and along Wenlock Edge to Benthal Edge near Coalbrookdale, as well as at the places just men-



Fossil Group No. 7.
Wenlock Fossils.

a. Acervularia luxurians.
b. Omphyma turbinatum.
c. Atrypha reticularis.
d. Strophomena depressa.
e. Strophomena euglypha.
f. Spirifer plicatellus.
g. Euomphalus discors.

tioned as showing Woolhope Limestone, and at the Castle Hill and Wrens Nest near Dudley; as also near the town of Walsall in Staffordshire, and in the neighbourhood of Usk in Monmouthshire.

Characteristic Fossils.—In all these places the beds, especially the limestones, abound in fossils, of which the following list is a selection that includes the most abundant and characteristic species. Many of the species, however, which abound in the greatest profusion in the

Wenlock rocks, are to be found, though rarely, in either earlier or later formations, or in both. These, then, are not characteristic in the sense of being peculiar to the Wenlock rocks, but as being more abundant in them than elsewhere. Here, too, as in some other parts of the

Fossil Group No. 3.
Wenlock Fossils.

a. Pseudocrinites quadrifasciatus.
b. Periechocrinus moniliformis.
c. Calymene Blumenbachii.
d. Phacops caudatus.
e. Bellerophon dilatatus.
f. Orthoceras annulatum.

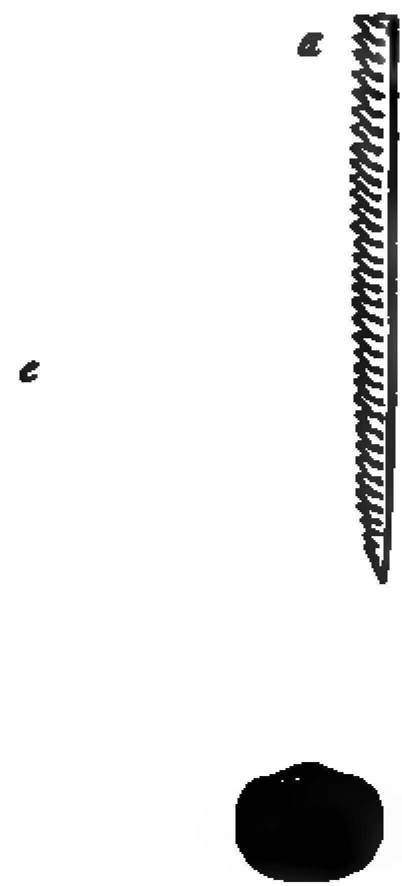
geological series, it is the assemblage of fossils that becomes characteristic; any one or two of these species may be found in some other groups, but in no other are they all assembled together in the abundance in which they occur in the Wenlock rocks.

Amorphozoa	? Stromatopora striatella (*Bala and Llandovery*)	Sil. foss. 52.
Actinozoa .	Acervularia luxurians . . .	Foss. gr. 7, *a*.
	Alveolites repens and Labechei . .	Sil. foss. 18.
	Favosites Gotlandicus (*Bala to Ludlow*)	Sil. foss. 17.
	——— fibrosus (*Llandovery to Ludlow*)	Sil. foss. 31.
	Heliolites Grayi.	

Actinozoa .	Omphyma turbinatum (*Bala to Wenlock*)	Foss. gr. 7, *b*.
	Petraia bina (*and Llandovery*) . .	Sil. foss. 53, pl. 38.
	Syringopora bifurcata (*Llandovery to Ludlow*)	Sil. foss. 20.
	Stenopora fibrosa (*Llandeilo to Ludlow*)	Sil. foss. 17.
Hydrozoa .	Graptolithus Flemingii . . .	Q. Geol. Jour. viii. p. 390.
Polyzoa .	Cellepora favosa.	
	Ceriopora affinis.	
	Discopora antiqua	Sil. foss. pl. 41.
	Fenestella Lonsdalei. . . .	*Ibid.*
	Ptilodictya scalpellum (*and Llandovery*)	Sil. foss. 51.
Brachiopoda	Atrypa reticularis (*Llandovery to Ludlow*)	Foss. gr. 7, *c*.
	Orbiculoidea Forbesii . . .	Davidson, Sil. Brach.
	Obolus transversus.	
	Orthis elegantula (*Llandeilo to Ludlow*)	Sil. foss. pl. 5, 9, 20.
	——— rustica.	
	Pentamerus galeatus (*and Ludlow*) .	Sil. foss. pl. 21.
	Retzia Baylei	Sil. foss. 57.
	Rhynchonella navicula (*and Ludlow*).	Sil. foss. pl. 22.
	——— Wilsoni (*Llandovery to Ludlow*)	*Ibid.*
	Siphonotreta Anglica . . .	Sil. foss. 58.
	Spirifer plicatellus (*Llandovery to Ludlow*)	Foss. gr. 7, *f*.
	Strophomena depressa (*Bala to Ludlow*)	Foss. gr. 7, *d*.
	——— euglypha (*Llandovery to Ludlow*)	Foss. gr. 7, *e*.
Conchifera.	Cardiola fibrosa (*and Ludlow*) . .	Sil. foss. pl. 23.
	Pleurorhynchus equicostatus . .	Sil. foss. 60.
	Modiolopsis antiqua. . . .	Sil. foss. pl. 23.
	Mytilus Chemungensis . . .	Mem. G. S. ii. p. 365.
	Pterinea retroflexa (*Llandovery to Ludlow*)	Foss. gr. 9, *e*.
Gasteropoda	Acroculia haliotis (*and Llandovery*) .	Sil. foss. pl. 24.
	Chiton Grayanus.	
	Euomphalus discors	Foss. gr. 7, *g*.
	——— funatus (*Llandovery to Ludlow*)	Sil. foss. pl. 25.
	——— rugosus	*Ibid.* 24.
	Murchisonia Lloydii (*and Ludlow*) .	*Ibid.*
Heteropoda	Bellerophon dilatatus (*Bala to Wenlock*)	Foss. gr. 8, *e*.
	——— Wenlockensis. . .	Sil. foss. pl. 25.
Pteropoda .	Conularia Sowerbyi (*Bala to Ludlow*)	*Ibid.*
	Theca anceps (*and Ludlow*) . .	Mem. G. S. ii. p. 355.
Cephalopoda	? Lituites Biddulphii . . .	Sil. foss. pl. 31.
	Orthoceras annulatum (*Bala to Wenlock*)	Foss. gr. 8, *f*.
	——— Maclareni . . .	Sil. foss. 25.
	——— ventricosum . . .	Q. J. Geol. Soc. ii.
Echinodermata	Actinocrinus pulcher . . .	Pal. foss. p. 1.
	Crotalocrinus rugosus . . .	Sil. foss. 56.
	Cyathocrinus goniodactylus . .	*Ibid.* pl. 14.
	Echino-encrinites armatus . . .	*Ibid.* 55.
	Eucalyptocrinus decorus . . .	*Ibid.* pl. 14.
	Marsupiocrinus cælatus . . .	*Ibid.* 56.
	Periechocrinus moniliformis (*and Llandovery*)	Foss. gr. 8, *b*.
	Pseudocrinites quadrifasciatus . .	*Ibid.* *a*.
	Taxocrinus tesseracontadactylus .	Sil. foss. pl. 14.
Annelida .	Cornulites serpularius (*Llandovery to Ludlow*)	Sil. foss. pl. 16.

Annelida .	Serpulites longissimus (*and Ludlow*) .	Sil. foss. pl. 16.
	Tentaculites ornatus (*Bala to Wenlock*)	*Ibid.*
Crustacea .	Acidaspis Barrandii	Sil. foss. 65.
	Ampyx parvulus (*and Ludlow*) . .	Mem. G. S. p. 350.
	Beyrichia Klœdeni (*from Bala to Tilestone*)	Sil. foss. 63.
	Calymene Blumenbachii (*from Bala to Ludlow*)	Foss. gr. 8, *c.*
	Cyphaspis pygmæus	Dec. G. S. 7.
	Encrinurus variolaris . . .	Sil. foss. 65.
	Homalonotus delphinocephalus . .	*Ibid.* 17.
	Illænus Barriensis (*and Llandovery*) .	Dec. G. S. ii.
	Lichas Anglicus (*and Ludlow*) . .	Sil. foss. 64.
	Phacops caudatus (*Llandovery to Ludlow*)	Foss. gr. 8, *d.*
	Proetus latifrons (*Llandovery to Ludlow*)	Sil. foss. 65.
	Sphærexochus mirus (*and Bala*) .	*Ibid.*
	Staurocephalus Murchisonii (*Bala to Wenlock*).	

Ludlow Group.—6. The Lower Ludlow Rock of Shropshire is at its base not unlike the Wenlock shale—a dark sandy shale, with



Fossil Group No. 9. Ludlow Fossils.

a. Graptolithus priodon. *b.* Orthis lunata. *c.* Pentamerus Knightii. *d.* Rhynchonella nucula. *e.* Pterinea retroflexa. *f.* Avicula Danbyi.

spheroidal calcareous concretions, becoming more sandy and flaggy above, generally of a pale-greyish or greenish-brown colour. It is

usually soft, and easily decomposing, so as to receive the local name of mudstone. The shales are often capped by beds of impure fuller's

Fossil Group No. 10.
Ludlow Fossils.

a. Cyclonema corallii. c. Palæocoma Colvini.
b. Protaster Miltoni. e. Orthoceras bullatum.
f. Phragmoceras ventricosum.

earth (provincially called walker's earth),* which support the Aymestry limestone.

7. **The Aymestry Limestone** is a dark grey limestone, rarely so thick or so pure as the Wenlock limestone often is. In South Staffordshire the workmen call the Wenlock "the white limestone," and the Aymestry "the black limestone." It is generally evenly-bedded and flag-like, being usually earthy or argillaceous, with small concretions. It often dies away into a mere band of calcareous nodules.

8. **The Upper Ludlow Rock** greatly resembles the lower, being a slightly micaceous sandy shale or flag, or soft argillaceous sandstone (mudstone), generally thin-bedded, of bluish-grey colour within,

* Walker, that is fuller. The old Saxon word *walk* or *wauk*, in the sense of *to full* (cloth), is not yet obsolete in the north.

weathering externally to a rusty-brown or greenish-grey. Large spheroidal concretions occur in it. The upper part of these beds passes by insensible gradations into red sandy flags, locally called tile-stones.

9. The Tilestones.—In Shropshire the gradation from the greyish or greenish Upper Ludlow rocks into the overlying red beds is rather a rapid one. There occur, just near the junction, one or two little bands, called *bone-beds*, consisting of the agglutinated fragments of fish and crustacea, which may be assigned to one or other group. The Downton Castle building-stone, a light-coloured, thin-bedded, slightly-micaceous sandstone, lies above these bone-beds.

In South Wales, about Llandovery and Llandeilo, the Upper Silurian rocks lose all their distinctive limestones, and can only be treated as one group of Upper Silurian, distinct from the Lower Silurian below. They are usually vertical, and as we pass across their edges we find the upper beds alternating with red beds, and gradually passing into a mass of red rocks above—fossils occurring wherever the beds happen not to be red. On the banks of the river Sawdde, near Llangaddock, there occurs a section, described by Sir H. De la Beche, of the upper part of which the following is an abstract:—

	Feet.
5. Grey micaceous, laminated sandstone, *fossiliferous*	390
4. Red sandstones, marls, and conglomerates	700
3. Purplish-grey micaceous sandstones, etc., *fossiliferous*	370
2. Band of red conglomerate.	
1. Grey and brown sandstones, flagstones, and shales, often very *fossiliferous*	2000

Below No. 1 we come down into Lower Silurian beds, while above No. 5 the beds are all red, and, so far as is known, quite unfossiliferous. The fossils in all the beds from 1 to 5 are Upper Silurian fossils, and the top of the group 5 is taken in the maps of the Geological Survey as the boundary of the Upper Silurian, all above being considered to be Old Red Sandstone. If we take groups 2 to 5 as Tilestones, we shall get a thickness of nearly 1500 feet for that subdivision.*

Characteristic Fossils.—The fossils of the Ludlow group amount to more than 500 species, of which the following list contains the most characteristic forms:—

Actinozoa	Cyathaxonia Siluriensis	M'Coy, Pal. foss. p. 36.
Hydrozoa	Graptolithus priodon (*Bala to Ludlow*)	Foss. gr. 9, *a*.
Brachiopoda	Discina rugata (*and Wenlock*)	Sil. foss. pl. 20.
	——— striata	*Ibid.*
	Lingula cornea	Sil. foss. 23.
	——— lata	Sil. foss. pl. 20.
	——— striata	*Ibid.*
	Orthis lunata	Foss. gr. 9, *b*.
	Pentamerus Knightii (*and Wenlock*)	*Ibid. c.*
	Rhynchonella nucula (*Llandovery to Ludlow*)	*Ibid. d.*

* See *Mem. Geol. Sur.* vol. i. p. 23; and Sheet 41 of the Geol. Sur. Map. On the red colour of strata, and on the connection between that colour and absence of fossils, see a paper by Professor Ramsay (*Quart. Journ. Geol. Soc.* 1871), and the remarks at the beginning of the account of the Old Red Sandstone in the present Manual.

Conchifera.	Avicula Danbyi	Foss. gr. 9, *f*.
	Anodontopsis (several species) .	M'Coy, Pal. foss. p. 271-2.
	Ctenodonta Anglica (*Llandovery to Ludlow*)	Sil. foss. pl. 23.
	Cucullella Cawdori . . .	Sil. foss. pl. 34.
	Goniophora cymbæformis (*and Llandovery*)	*Ibid.* pl. 23.
	Modiolopsis complanata . .	*Ibid.*
	Orthonota (several species).	
	Pterinea retroflexa (*Llandovery to Ludlow*)	Foss. gr. 9, *e*.
Gasteropoda	Acroculia euomphaloides . .	M'Coy, Sil. foss. p. 290.
	Cyclonema corallii . . .	Foss. gr. 10, *a*.
	Euomphalus carinatus . . .	Sil. foss. pl. 24.
	Holopella cancellata (*Bala to Ludlow*)	Sil. foss. 15.
	Loxonema sinuosum . . .	Sil. foss. pl. 24.
	Murchisonia articulata (*and Llandovery*)	*Ibid.*
	Natica parva	*Ibid.* 25.
	Pleurotomaria undata . . .	*Ibid.* 24.
Heteropoda.	Bellerophon expansus (*and Llandovery*)	Sil. foss. pl. 25.
Pteropoda .	Conularia subtilis.	
	Ecculiomphalus lævis (*and Llandovery*)	Sil. foss. pl. 25.
	Theca Forbesii (*and Wenlock*) .	Q. J. Geol. Soc. ii. p. 314.
Cephalopoda	Ascoceras Barrandii . . .	Sil. foss. 63.
	Lituites articulatus . . .	Sil. foss. pl. 31.
	Orthoceras bullatum (*and Llandovery*)	Foss. gr. 10, *e*.
	Phragmoceras ventricosum (and five other species)	*Ibid.* *f*.
Echinodermata	Palæaster Ruthveni . . .	Sil. foss. 57.
	Palæocoma Colvini (and three other species)	Foss. gr. 10, *c*.
	Protaster Miltoni (and three other species	*Ibid.* *b*.
	Taxocrinus Orbignyi . . .	M'Coy, Pal. foss. p. 53.
Annelida .	Crossopodia lata	M'Coy, Pal. foss. p. 130.
	Serpulites dispar	*Ibid.* Ap. p. 1.
	Tentaculites tenuis . . .	Sil. foss. pl. 16.
	Trachyderma coriaceum (and squamosum)	Mem. G. S. ii. p. 331.
Crustacea .	Acidaspis coronata . . .	Q. J. Geol. Soc. xiii. p. 210.
	Beyrichia siliqua.	
	Calymene Blumenbachii (*Bala to Ludlow*)	Foss. gr. 8, *c*.
	Ceratiocaris Murchisonii (and ten other species)	Sil. foss. pl. 19.
	Encrinurus punctatus (*Llandovery to Ludlow*)	Sil. foss. 15.
	Eurypterus abbreviatus (and six other species)	Q. J. Geol. Soc. vol. xv.
	Homalonotus Knightii . . .	Sil. foss. pl. 19.
	———— Ludensis.	
	Lichas anglicus (*and Wenlock*) .	Sil. foss. 64.
	Phacops caudatus, Downingiæ, and longicaudatus (*and Wenlock*) .	Sil. foss. pl. 17.
	Proetus latifrons (*Llandovery to Ludlow*)	Sil. foss. 65.
	Pterygotus bilobus . . .	Sil. foss. 26.

Crustacea .	Pterygotus problematicus (and several other species)	Dec. G. S. 10.
Fish . . .	Onchus Murchisonii . . .	Sil. foss. pl. 35.
	——— tenuistriatus . . .	*Ibid.*
	Plectrodus mirabilis . . .	*Ibid.* 35.
	———- pustuliferus . . .	*Ibid.* 35.
	Pteraspis Banksii	Sil. foss. 68.
	——— truncatus . . .	*Ibid.*
	Sphagodus pristodontus . .	Sil. foss. pl. 35.

Characteristic Fossils of the Tilestones.—The following fossils have been found in what are styled "passage beds," which lie above the Downton Castle stone, and show a conformable gradation from the Upper Ludlow to the Old Red Sandstone :—

Brachiopoda	Lingula cornea (*also in Ludlow*) .	Sil. foss. 23, pl. 34.
Conchifera .	Telluites affinis	Pal. foss. pl. 1, k.
Gasteropoda	Platyschisma helicites (*also in Ludlow*)	Sil. foss. 26, pl. 34.
Crustacea .	Astacoderma (nine species) . .	Q. J. G. S. xvii. p. 542.
	Beyrichia Klœdeni (*from the Llandovery*)	Sil. foss. 63.
	Eurypterus linearis (*also in Ludlow*)	Q. J. G. S. xv.
	——— megalops (*peculiar*) .	*Ibid.*
	——— pygmæus (*also in Ludlow*)	Sil. foss. 66.
	Leperditia *sp.* (*also in Ludlow*) .	Ann. Nat. Hist. xvii. 91.
	Pterygotus Banksii . . .	Sil. foss. 67.
	——— Ludensis (*peculiar*) .	*Ibid.*
	Parka decipiens, eggs of Pterygotus (*peculiar*).	
Fish . . .	Auchenaspis Salteri . . .	Q. J. G. S. xiii. pl. 11.
	——— ornatus . . .	Sil. foss. 22.
	Cephalaspis Murchisonii . .	Sil. foss. 23.
	Onchus Murchisonii (*also in Ludlow*)	Sil. pl. 35.
	Plectrodus mirabilis (*do.*) . .	*Ibid.*
	Pteraspis Banksii (*do.*) . . .	Sil. foss. 68.

The description of the Upper Silurian rocks just given applies to them throughout Shropshire and Staffordshire, Herefordshire and Worcestershire, Monmouthshire and Gloucestershire.* If we proceed from that district into either North Wales or, as already remarked, into South

* In Sheet 30 of the Horizontal Sections of the Geological Survey, which crosses Clun Forest, we have the following series described by Mr. Aveline :—

		Feet.
Supposed Old Red Sandstone.	Red marl and fissile grey micaceous sandstone (used for tiles) with thicker beds of light-coloured sandstone	1500
Ludlow Group.	Sandy, flaggy, brown shales, and dark brown sandstone, upper beds very fossiliferous, lower quarried for flagstone	6000
Wenlock Group.	Greyish-brown and blue sandy argillaceous shale, passing down into thick, grey gritty sandstones, with bands of dark slate (Denbighshire sandstones).	5000

In Sheet 4, which runs over Mynnydd bwlch-y groes, near Llandovery, the section crosses the edges of the following beds, all vertical :—

		Feet.
Red beds of supposed Old Red Sandstone.		
Tilestones—Laminated, grey, micaceous sandstone, fossiliferous		800
Ludlow and Wenlock.	Sandstones, thick above, thinner below, having grey shales and calcareous bands interstratified, with most shales near the base .	5500
Llandovery.	Pale, blue, green, and brown shales (Tarannon)	600
	Thick beds of coarse sandstone, with layers of Pentameri . . .	300

Wales, a great change takes place in them, since all the limestones die out and disappear, and the clays and shales pass into hard slates and flags, while coarse sandstones and fine hard grits make their appearance among them. In the Clun Forest district, and thence through Radnor Forest down to Llandeilo towards the south, or in the Long Mountain (between the Stiperstones and the Breiddens) on the north, it is barely possible to separate the Upper Silurian into two groups—the Ludlow and the Wenlock. In all these places they pass conformably and gradually up into the overlying red series (Tilestones or Passage beds) which have hitherto been considered the base of the Old Red Sandstone. Farther north, in Denbighshire, even this separation has been found impracticable. The Upper Silurian consists of the Tarannon shales, probably representing the Llandovery beds, and the Denbighshire sandstones, which represent the lower part of the Wenlock shale, and pass up into a great series of dark flags and slates, which represent the upper part of the Wenlock group, and possibly more or less of the Ludlow series. These beds are very highly inclined and greatly denuded, and small patches of Old Red Sandstone lie here and there, nearly horizontally, across their often vertical edges, the Silurian rocks striking east and west, while the Old Red Sandstone ranges from south to north. These Denbighshire flags contain an abundance of large Orthoceratites,* as well as groups of Crinoids in some places, and other fossils (*Cardiola interrupta*, etc.), which prove their Upper Silurian character independently of their lying above the Bala beds of the Berwyns, and Cyrn y Brain, and those of Merioneth and Caernarvon.†

CUMBERLAND, etc.—According to Professor Sedgwick the following are the typical groups of rocks deposited during the Upper Silurian period in the north of England :—

3. Kendal group = Ludlow rocks.
2. Ireleth slates = Wenlock rocks.
1. Coniston grits = May Hill sandstone.

1. The Coniston grits have few fossils, and their identity with the May Hill sandstone is therefore doubtful, although very probable.

2. The Ireleth slate group is divided into four stages :—*a*, Lower Ireleth slate ; *b*, Ireleth limestone ; *c*, Upper Ireleth slate ; *d*, Coarse slate and grit. Fossils are rare, but generally of the Wenlock type.

3. The Kendal group is divided into three stages : *a*, A great group of flags and grits ; fossils abundant and of the Lower Ludlow type. *b*. Thick grit and flagstone, with bands of coarse slate ; fossils locally abundant, and of Upper Ludlow type ; *c*, Tilestones, resembling those of Shropshire, etc.‡ Four species of star-fish have been found by Pro-

* Called at one time Creseis, by E. Forbes : *Geol. Journ.* vol. i. p. 146, and ii. p. 314.
† See Maps 71 and 74, and Sections Nos. 38 and 39 of the Geological Survey.
‡ Sedgwick, *Synopsis of Classification*, etc.

fessor Sedgwick in the Kendal group (stage *b*), of which *Uraster primævus* is the most abundant, and *Protaster Sedgwickii* the most interesting, as when first described it was considered to be the only known fossil representative of the Euryalidæ,* although better specimens, since obtained, show it to have been an abnormal form of the Ophiuridæ.†

SCOTLAND.—Upper Silurian rocks are at present known to occur in three localities in Scotland, but in none of these have their relations to the Lower Silurian series been accurately determined. On the south side of the Silurian uplands of Galloway, Wenlock fossils have been obtained near Kirkcudbright.‡ On the north side of these high grounds, a thick series of Upper Silurian rocks, with *Pterygotus*, *Trochus helicites*, *Lingula cornea*, and other fossils, graduates upward into the base of the Old Red Sandstone, while in the Pentland Hills a much more abundantly fossiliferous series, also passing up into the Old Red Sandstone, contains representatives of both the Wenlock and Ludlow group.§ In the valley of the Girvan, Ayrshire, representatives of the Llandovery group are well exhibited; but though they contain some Upper Silurian forms, their general character is that of the lower Llandovery rocks.

IRELAND.—Representatives of the Llandovery beds are to be found largely in Galway, about Maam, and the south-west end of Lough Mask, some of the upper beds being probably of Wenlock age. This is the case with the beds of Ughool, near Ballaghadereen, and possibly with those of Lisbellaw, south of Enniskillen. In all these places great conglomerates abound, containing rounded blocks of syenite of one or two feet in diameter. Beds, probably of Llandovery age, are to be found also in the Cratloe Hills of Limerick. On the west flank of Cahirconree, in Kerry, some limestone bands contain fossils which have been determined by Mr. W. H. Baily, and are believed to be of Wenlock age.

At the extremity of that promontory, between Ferriters Cove and Dunquin, and thence to Smerwick Harbour, certain beds occur which appear to represent both the Wenlock and Ludlow groups, since crowds of fossils, characteristic of those beds, are to be found there. A certain line was drawn by the late Mr. Du Noyer, beneath which Wenlock species abound, while above it are many Ludlow species, including, in some places, many specimens of *Pentamerus Knightii*. These beds are, however, greatly disturbed and confused, and bent into violent contortions, if not inverted. Certain beds of purple, and green, and yellow sandstones, etc., lie apparently beneath the Wenlock beds, and graduate up into them, peculiar conglomerates occurring both in the fossiliferous beds and in the beds below them. These are called by the Geological Survey by the provisional name of the Smerwick beds. Over the

* *Mem. Geol. Survey*, Dec. 1. † *Siluria*, p. 225.

‡ *Quart. Journ. Geol. Soc.* iv. 206; and vii. 54. See also Geikie on Silurian Rocks of Scotland (*Trans. Geol. Soc. Glasgow*, iii. 93).

§ See *Siluria*, pp. 159-163, and the authorities there cited.

Ludlow beds, again, there sets in a vast thickness of green and purplish grits, interstratified with red shales, and having in the upper beds purple conglomerates, with pebbles containing Llandovery fossils. These we call the Dingle beds. They appear to occupy the same position as the red beds above the Ludlow rocks in Shropshire and Herefordshire, in South Wales and in Scotland, but no fossils have yet been found in them in Ireland. They will be mentioned again in the next chapter.

Foreign Localities.

Bohemia.—M. Barrande has divided the Upper Silurian rocks of Bohemia into four stages (étages): Stage E, Lower Limestone; Stage F, Middle Limestone; Stage G, Upper Limestone; Stage H, Overlying schists. He shows from an abundant fauna that these rocks in Bohemia are closely paralleled by the Upper Silurian series of Britain, though he does not identify any one of his groups with any one of our British subdivisions.*

Scandinavia.—The Lower Silurian rocks of the south of Norway are overlaid with strata, in which, as in the Lower Llandovery beds of Wales, there is a mingling of Lower and Upper Silurian forms of life, and above which come true Upper Silurian rocks. The Wenlock group is well represented; the Ludlow rocks less distinctly. In the south of Sweden, however, true Upper Ludlow fossils occur. It is interesting to find that though in thickness of strata the Scandinavian Silurian series is a poor representative of the enormous depth of the system in Britain, it yet represents the various palæontological horizons with wonderful completeness. From the "primordial zone" to the top of the Upper Silurian groups, the whole system in the Christiania basin does not reach a thickness of 2000 feet, yet, according to Sir R. Murchison, it "represents the whole of the vastly expanded British series."†

North America.—The rocks of this region of the age of the Upper Silurian period, are—

	Lower Helderberg Group (Ludlow rocks)	Upper Pentamerus limestone Encrinal limestone Delthyris shaly limestone Lower Pentamerus limestone Tentaculite limestone	*Pentamerus pseudo-galeatus.* *Pentamerus Verneullii, etc.* *Pentamerus galeatus.* *Tentaculites ornatus, etc.* } 300 feet.
Wenlock	Onondago Group	Onondaga salt group, a grey ash-coloured shale, with gypsum and rock-salt	*Atrypa, Delthyris, Pentamerus, Merista, Murchisonia, etc.*
	Niagara Group	Niagara limestone, compact grey limestone, resting on Niagara shale	Numerous corals in limestone, *Orthis, Spirifer, etc.*
Upper Llandovery	Clinton Group	Clinton rocks (2400 feet) *c.* Variegated red marls and calcareous shales *b.* Shales and argillaceous limestone and calcareous sandstone *a.* Greenish and yellowish slates with ferruginous sandstone	*Pentamerus ovalis* in upper part; *P. oblongus* in lower beds; *Lingula oblonga, Leptæna depressa; Calymene Blumenbachii, etc.*

* See his *Système Silurien de la Bohème;* and *Siluria*, p. 274.

† *Siluria*, p. 352.

It does not appear that in this table there is any exact equivalent of the Upper Ludlow rocks, and there appears to be a break between the top of the Lower Helderberg group and the next formation, or Oriskany Sandstone, which, resting in denuded hollows of that group, is regarded as the base of the Devonian system.

Volcanic Rocks of Silurian Period in Britain.

In accordance with the plan proposed on a previous page,* we proceed to add to the foregoing account of the stratigraphical and palæontological characters of the Silurian rocks of Britain, some references to the evidence which these rocks furnish as to contemporaneous volcanic activity. Neither in the Laurentian nor in the Cambrian formations of this country, have any traces of such activity as yet been found. The Silurian volcanoes are thus the most ancient of which we possess here any record.

Lower Silurian.†—The oldest recognisable volcanic rocks in this country belong to the lower Silurian period. They are best displayed in North Wales, where, as was shown long ago by Sir Roderick Murchison, they rise into conspicuous ranges of hills. Two principal epochs of eruption have been detected by Professor Ramsay and his colleagues of the Geological Survey. One of these occurred during the deposition of the Llandeilo rocks, and is indicated by the igneous rocks of Aran Mowddwy, Cader Idris, Arenig and Moelwyn ; the other is marked by those of the Snowdon district which lie among the Bala beds. These volcanic rocks consist partly of massive sheets of felstone, varying in texture and colour, and partly of thick accumulations of tuff or ash. The former are true lava-flows, the latter point to frequent showers of volcanic dust, and to the settling of such dust and stones on the sea-bottom, where they mingled with the ordinary sediment, and with shells, corals, and other organisms. Some of these ashy deposits attain a great thickness. Thus, at Cader Idris, "they are about 2500 feet thick, the accumulated result of many eruptions." Northwards, this mass thins entirely away, and the ordinary sedimentary strata take its place. Equally local are the massive beds of felstone which represent the submarine lava-flows of the time. Sometimes they still preserve the slaggy vesicular character which marked their surface when the melted rock was in a state of motion along the sea-bottom. By this and other evidence of a like tendency we learn the existence and position of true submarine volcanoes during the lower Silurian period in Wales.‡ Northwards, in the Lake District, Professor Sedgwick has found similar proofs of volcanic action among the lower Silurian rocks of that region, and these rocks are now being worked out in detail by Mr. Aveline and his colleagues of the Geological Survey.

* *Ante*, p. 284. † See *Brit. Assoc. Rep.* 1867, Address to Geological Section.

‡ See Murchison, *Siluria*, p. 83. Ramsay, Descriptive Catalogue of Rock Specimens in Jermyn Street Museum, 3d edit. p. 8. *Mem. Geological Survey*, vol. iii. p. 21, *et passim*.

No very distinct traces of contemporaneous volcanic activity have yet been detected among rocks of this age in Scotland.

Among the lower Silurian rocks of the south-east of Ireland beds of tuff and felstone are interstratified, resembling in general character and mode of occurrence those of Wales, but on a much smaller scale. It has been observed that the Silurian fossils of that region occur only in the upper part of the series, in the neighbourhood of the trap-rocks and calcareous bands.*

Upper Silurian.—In Wales volcanic action does not appear to have outlasted the lower Silurian period, but in the south-west of Ireland, among the headlands of Kerry, massive sheets of tuff are intercalated in grits and slates, which, from their fossils, have been assigned to the age of the Wenlock series.†

* *Memoirs of Geol. Surv. Ireland.* Explanations to Sheets 102, 111, 147, 167.

† *Mem. Geol. Surv. Ireland.* Explanations to Sheet 160, etc., p. 21.

CHAPTER XXXII.

DEVONIAN AND OLD RED SANDSTONE PERIOD.

THIS period is called Devonian, because the rocks which were deposited during its continuance occupy a large part of Devon. All rocks which were formed after the uppermost of those which can be properly called Silurian, and before the lowest of any which can be properly called Carboniferous, may be classed as Devonian rocks, and looked upon as records of Devonian time. The older term "Old Red Sandstone," however, is retained as the designation of those thick masses of red sandstone and conglomerate which in Wales, Scotland, and Ireland, intervene between the Silurian and Carboniferous systems, and are either unfossiliferous or contain chiefly the remains of ganoid fish. The true Devonian rocks of Devon and Cornwall are undoubtedly of marine origin, but the Old Red Sandstone, as suggested by Mr. Godwin Austen, and more recently insisted on by Professor Ramsay, may possibly have been deposited in great lakes or inland sheets of water.

To what extent the Devonian and Old Red Sandstone rocks of Britain are contemporaneous has not been clearly ascertained. They occupy corresponding portions in the geological series, but they are not found touching each other, nor do they possess any common palæontological evidence by means of which they may be satisfactorily compared. In Russia and America recognised Old Red Sandstone fishes have been found in strata containing Devonian fossils.* The smooth grey marbles of Plymouth may be on the same horizon as some of the coarse conglomerates of Hereford or Wales, that is, they may have been formed at the same time in different places. Just as the pebble beaches of the British coasts and the coral reefs of the tropics are, as contemporaneous deposits, included in the same "Recent or Human Period," so these old dissimilar rocks might all belong to the "Devonian Period." It is, however, quite possible that the slates and limestones of Devon, and the red sandstones of South Wales, although each deposited within the same great period, are not strictly contemporaneous, but were formed at different parts of the period. Or it is possible that the red sandstone series of South Wales is not a continuous series—that the lower part of it, at all events, is older than any of the Devon series, while the upper part may be newer than much of that series.

* See *Siluria*, chaps. xi. and xviii.

Since there are thus two distinct types of strata in Britain, each lying between the Silurian formations below and the Carboniferous above, it will be of advantage to describe each type separately, along with what appear to be or are now known to be its foreign equivalents.

Devonian.*

In North Devon the order of succession of the Devonian rocks has been ascertained to be as follows :—

3. *Upper Devonian* (Barnstaple and Marwood Beds).—Consisting of slates, schists, and calcareous bands, containing fossils also found in the Carboniferous system above.
2. *Middle Devonian* (Ilfracombe Beds).—Grey schists and *Stringocephalus* limestone.
1. *Lower Devonian* (Lynton Beds).—Red sandstones and conglomerates resting on schists and slates, base not seen.

Fossil Group No. 11.—Devonian.

a. Stromatopora placenta.	d. Stringocephalus Burtini.
b. Bronteus flabellifer.	e. Pleurotomaria aspera.
c. Calceola sandalina.	f. Clymenia striata.

* The late author of this Manual entertained the belief that the so-called Devonian rocks are the equivalents of the lower Carboniferous rocks of Ireland,—a view which is not generally accepted by geologists, but of which the student will find a fuller resumé in the Appendix.

Professor Sedgwick arranges the rocks of South Devon into the following groups:—

3. *Dartmouth Slate Group.*—Coarse roofing slates and quartzites, ending upwards with beds of red, green, and variegated sandstone.

2. *Plymouth Group.*
   - *c*, Coarse red sandstone and flagstone.
   - *b*, Calcareous slates.
   - *a*, Great Devon limestone.

1. *Liskeard or Ashburton Group.*

The whole of the rocks of Devon and Cornwall are greatly disturbed and contorted, often even inverted, so that in the country about the Dodman, south-west of St. Austell Bay, some of the upper rocks dip apparently beneath others which are, by their fossils, of Silurian age. For this reason the district is one which is not well calculated to form a typical district, and any conclusions drawn from it require very strict testing and verification in other localities where the rocks have been left more undisturbedly in their original order of superposition.

*Characteristic Fossils from Devonshire and Cornwall.**

		Lower.	Middle.	Upper.
Plants	Knorria dichotoma	—	—	*
	Adiantites Hibernicus	—	—	*
Cœlenterata	Cyathophyllum cæspitosum	—	*	*
	Favosites cervicornis	*	*	—
	Petraia Celtica	*	*	*
	Pleurodictyum problematicum	*	*	—
Annelida	Tentaculites annulata	—	*	—
Crustacea	Bronteus flabellifer	—	*	—
	Cypridina serrato-striata	—	—	*
	Homalonotus Herschellii ?	*	—	—
	Phacops granulatus	—	*	*
	——— laciniatus	*	*	*
	——— latifrons	—	*	*
Brachiopoda	Atrypa desquamata	*	*	*
	——— reticularis	*	*	*
	Chonetes Hardrensis	*	*	*
	Meristella plebeia	—	*	—
	Orthis granulosa	*	*	—
	Productus prælongus	—	—	*
	Spirifer lævicostus	*	*	—
	——— lineatus	—	*	*
	——— speciosus	*	*	—
	Stringocephalus Burtini	—	*	—
Lamellibranchiata	Avicula Damnonienses	—	—	*
	——— subradiata	—	*	*
	Cucullela amygdalina	—	*	*
	——— Hardringii	—	—	*
Gasteropoda	Euomphalus annulatus	—	*	—
	Murchisonia angulata	—	—	*

* R. Etheridge, *Quart. Journ. Geol. Soc.* vol. xxiii.

Characteristic Fossils from Devonshire and Cornwall—continued.

		Lower.	Middle.	Upper.
Gasteropoda . .	Pleurotomaria aspera . .	—	*	*
Nucleobranchiata	Bellerophon bisulcatus . .	*	*	*
	———— subglobatus .	—	*	*
Cephalopoda . .	Clymenia lævigata . .	—	*	*
	———— striata . . .	—	—	*
	———— undulata . .	—	—	*
	Goniatites subsulcatus . .	—	—	*

Volcanic Rocks of Devonian Age in Britain.

During the accumulation of the Devonian rocks of the south-west of England, volcanic action appears to have been well displayed in that region. Sir Henry De la Beche pointed out frequent proofs of this action in the strata extending from the slates and limestones of the middle Devonian series upwards into the lower part of the carboniferous system. He found both amygdaloidal lava-form rocks and trap-tuffs—the latter passing insensibly into the ordinary sedimentary strata. In some places the tuff contains fossils, and becomes so calcareous and so interlaced with bands of limestone as to have been quarried for lime. The "greenstones" are abundantly cellular and slag-like in character.*

Foreign Localities.

The following order of succession has been ascertained in Rhenish Prussia :—

Upper Devonian (Clymenia and Goniatite Limestone ; Cypridenen-Schiefer ; Kramenzel-Stein ; Flinz with Spirifer-Verneulii-Schiefer), consisting of schists with limestone and characterised by *Cypridinæ*, and by *Goniatites* and *Clymeniæ*.

Middle Devonian (Eifel Limestone ; Younger Rhenish Greywacke ; Lenne-Schiefer) composed of schists and sandstones with lenticular masses of limestone. In the limestone an abundant suite of fossils occurs, among the more characteristic of which are *Stringocephalus Burtinii*, *Uncites gryphus*, *Davidsonia Verneulii*, *Spirifer undiferus*, *Megalodon cucullatus*, *Cyathophyllum cæspitosum*, *Favosites polymorphus*, *Heliolites porosus*, *Phacops latifrons*, *Cryphæus punctatus*. Several icthyolites including *Coccosteus* have likewise been found.

Lower Devonian (Older Rhenish Greywacke ; Spiriferen-Sandstein, Wissenbach Slates, Système Rhénan) Slaty schists with sandstones, quartz-rocks, and occasional impure limestone. Characterised by *Spirifer hystericus*, *Sp. speciosus*, *Terebratula Archiaci*, *Pterineæ*, *Orthides*, *etc.*, *Phacops laciniatus*, *Ph. latifrons ; Homalonotus Ahrendi*, *H. armatus*, *etc.*†

North America.—In many parts of North America the Palæozoic rocks lie so regularly and undisturbedly, that they may probably be eventually taken as the true type of that part of the series which lies between the Silurian and Carboniferous formations. The following groups have hitherto been described as lying

* De la Beche, *Report on Devon and Cornwall*, pp. 51, 70 ; also *Brit. Assoc. Rep.* 1867. Address to Geol. Sect.

† See Murchison, *Siluria*, chap. xvi., and authorities there cited.

above those previously mentioned at p. 543, and below others, which belong undoubtedly to the Carboniferous period.

			Feet.
Upper		12. Catskill group or Old Red Sandstone—red shales and grey and red sandstones	2000 to 4000
		11. Chemung group—grey, blue, and olive-coloured shales, and grey and brown sandstones	1500 to 3200
		10. Portage group—fine-grained blue flag-stones, with blue shale partings	1700
Middle	Upper Helderberg Group.	9. Genesee slate—brownish-black and bluish-grey slate	30 to 300
		8. Tully limestone, according to Bigsby	10 to 20
		7. Hamilton or Moscow Shale—grey shale with dark brown sandstone	600
		6. Marcellus shale—black, with thin argillaceous limestone	150 to 300
		5. Corniferous limestone—light-grey or straw-coloured, with chert nodules	80 to 350
		4. The Onondaga limestone comes in here in New York, according to Bigsby, from	10 to 40
Lower		3. Schoharrie grit	10
		2. Caudagalli grit, argillaceo-calcareous thin-bedded sandstone	50 to 300
		1. Oriskany sandstone	70 to 700

It appears that the upper division contains fish of the genus *Holoptychius*, plants of the genera *Sigillaria* and *Lepidodendron*, and other fossils. The middle group contains Trilobites of the genera *Phacops*, *Proetus*, and *Homalonotus*, together with *Dalmanites* (a division of *Phacops*), *Atrypa reticularis*, and other fossils, together with, as stated, Old Red Sandstone fish, and shells of the genera *Goniatites* and *Producta*, as well as *Halysites catenularis*, and other Silurian forms, such as *Tentaculites*. The Oriskany sandstone contains *Orthis unguiformis* and other fossils, and *Spirifera macroptera* and *Pleurodictyum problematicum*.* Old Red Sandstone fish, of the genera *Asterolepis*, etc., occur with the marine shells.

Sir W. Logan assigns a thickness of 7000 feet to the Devonian rocks of Canada, but they thin away to nothing to the southwards, as on the Mississippi the Carboniferous rocks lie directly on the Silurian. From the Devonian series of New Brunswick and Nova Scotia, Dr. Dawson has in recent years disinterred and described upwards of eighty species of land-plants, belonging for the most part to genera which are found in the succeeding or Carboniferous system.†

Old Red Sandstone.

In Wales, in the border country between Wales and England, called by Sir Roderick Murchison Siluria, in Scotland and in Ireland, there lies between the Silurian rocks and those of Carboniferous age a great thickness of strata, differing very markedly from the Devonian rocks of Devon and Cornwall. To these the name of the Old Red Sandstone was in the early history of the science applied, to indicate that they consisted chiefly of sandstone, that they were red in colour, and that,

* See also Dr. Bigsby's paper on the Palæozoic Rocks of N. America, *Quart. Journ. Geol. Soc.* vol. xiv.

† See his papers in *Quart. Journ. Geol. Soc.*, xviii. and xix.

lying below the Coal-measures, they were 'Old' as contrasted with other red sandstones, which, lying above the Coal-measures, were 'New.' As a descriptive term for the rocks as developed in Britain, a better substitute could not be found; for though clays, limestones, conglomerates, and other rocks occur in the formation, and though various shades of purple, green, yellow, and even white occur, the fact remains that, as a whole, the strata really do consist mainly of red sandstones.

On the Red Colorisation of certain Formations.—Some remarks may be offered here in regard to some recent speculations as to the probable cause of the prevailing red colour of some formations. The Cambrian rocks, as we have seen, are often markedly red. The Old Red Sandstone, the Permian, and the Trias, to be yet described, are likewise distinguished by their red hues. In a paper recently read before the Geological Society of London, Professor Ramsay has called attention to the red colour of the Cambrian, Old Red Sandstone, Permian, and other formations, as furnishing evidence of the existence of ancient inland seas or lakes. He shows that the red strata are to a large extent unfossiliferous, and that where they lie upon and pass down conformably into fossiliferous beds, as the Old Red Sandstone of Wales and of Scotland does into the Upper Silurian, the fossils of the underlying formation become fewer in numbers and dwarfed in form as they are traced up into the red beds, until they finally disappear. This happens so frequently that the conclusion can hardly be avoided that the conditions under which the red beds were deposited were not favourable to life. Professor Ramsay connects the occurrence together of red colouring matter (peroxide of iron), gypsum, magnesian limestone, and beds or pseudomorphs of rock-salt, remains of plants, amphibian foot-prints, and rain-pittings, as parts of a whole series of phenomena which are not reconcilable with deposition in open sea, but in inland seas where the waters were capable of evaporation and concentration, and where, consequently, ordinary testaceous life could not flourish. He believes that in the case of the Old Red Sandstone of Britain (as distinguished from the Devonian series) we have before us proofs of a gradual shallowing of the Silurian sea, and of such additional geographical changes as sufficed to convert the bed of that sea in our area, first into brackish water and afterwards into one great fresh-water lake or series of lakes, in which a few of the old marine forms might partially survive, or into which their successors might find occasional access. In directing attention to the significance of the vast intercalated groups of red strata in the list of geological formations, he remarks that if his deductions as to the origin of these strata are correct, the geological record is by no means so barren of traces of ancient terrestrial conditions as it is commonly believed to be. In palæozoic, and partly in

mesozoic times, for instance, he considers that, from the close of the Silurian period onward to the epoch marked by the Rhætic beds, we have evidence of the presence in Europe of a long series of inland waters in which the Old Red Sandstone, great part of the Carboniferous formations, the Permian, Trias, and part of the Rhætic series, were successively deposited. Such continuity of terrestrial conditions implies, he thinks, probable continuity of terrestrial or lacustrine genera, if not species; and he believes it quite possible that such continental types of life might remain in existence during the passage of several geological periods. The identification of the *Hyperodapedon* of Elgin with a true triassic lizard, to be afterwards noticed, would thus be no necessary proof of the triassic age of the Elgin beds, but might, on the other hand, indicate the permanence of one of the forms of life of the palæozoic continents. Hence, while he has never seen any sound stratigraphical reason why the strata at Elgin yielding *Hyperodapedon*, *Stagonolepis*, etc., should be dissevered from the Old Red Sandstone, to which they were originally assigned, he finds in the palæontological argument for this separation no valid reason for the change, and therefore continues to believe that the reptile-bearing beds of Elgin are what they were until recently believed to be—members of the Old Red Sandstone.*

Scotland.—The Old Red Sandstone is better developed in Scotland than in the sister kingdoms. It may be regarded as occurring there in two types, one found to the north, the other to the south of the Grampian range. The southern type is marked by the abundance of its interbedded volcanic rocks, and by a comparative poverty of organic remains, though these do occur in sufficient numbers in a few localities. The northern type is distinguished by the absence of intercalated igneous rocks, and by a comparative abundance of fossils.

Southern type.—The Old Red Sandstone of the southern half of Scotland is divisible into three groups or series.

Upper.—Red and yellow sandstones and conglomerates of Berwickshire, Haddingtonshire, and Fife. Contain *Holoptychius*, *Pamphractus*, *Glyptopomus*, etc., with *Cyclopteris Hibernica*.

Middle.—Reddish, green, and grey sandstones, flagstones, and conglomerates, with abundant contemporaneous volcanic rocks; seen in the south-west of Ayrshire, where, in the upper part of the series, *Pterichthys major* has been found.

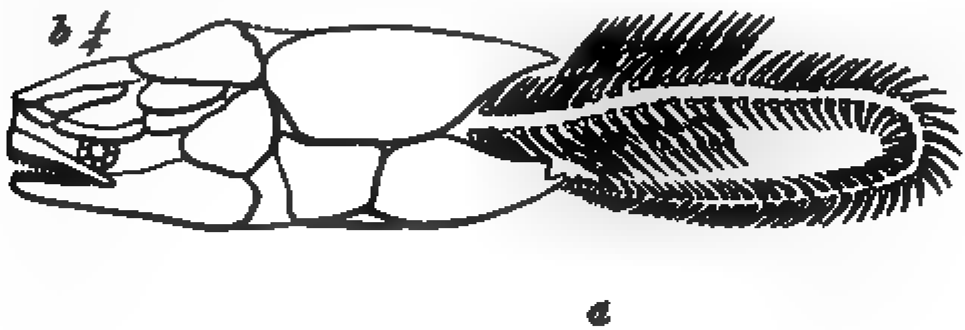
Lower.—Red, chocolate-coloured, and grey sandstones and shales, sometimes with enormous intercalated masses of contemporaneous volcanic rocks; the Sidlaw and Ochil Hills, Pentland Hills,

* The above abstract of Mr. Ramsay's paper has been made from a proof which he has been so good as to send to the Editor for the purpose, in anticipation of the publication of the paper itself in an early number of the *Quarterly Journal of the Geological Society*.

and the tract of hilly country stretching thence by the head of Nithsdale into Ayrshire—*Cephalaspis Lyelli, Pterygotus Anglicus;* numerous icthyolites in Forfarshire.

Of these groups, the lower, as developed in Edinburghshire and Lanarkshire, passes down conformably into the Upper Silurian. The upper group shades, in like manner, conformably into the overlying Carboniferous system. But the middle series is separated from both of the others by an unconformability.*

Northern type.—Three divisions have been ascertained to be traceable in the Old Red Sandstone of the north of Scotland by Sir Roderick Murchison, by whom the relations of these rocks were first fully



Fossil Group No. 12.

Fossil Fish of Old Red Sandstone.

a. Cephalaspis Lyellii. b. Coccosteus decipiens. c. Pterichthys latus.

described.† So far as yet known, they all pass conformably into each other, no evidence having been observed of either of the strong

* See Geikie, *Quart. Journ. Geol. Soc.*, vol. xvi. p. 312, and *Siluria*, p. 248.

† See his *Siluria*, chap. xi. and *Quart. Journ. Geol. Soc.*, vol. xv.: also his early memoir in conjunction with Professor Sedgwick, *Trans. Geol. Soc.*, 2d ser., vol. iii. p. 125.

unconformabilities so well marked in the southern part of the kingdom.

Upper.—Light red and yellow sandstones of Dunnet Head, and the Orkney and Shetland Islands, with plants of the genus *Calamites*.

Middle.—Grey and dark flagstones, occasionally calcareous and bituminous, covering a large area in Caithness, and extending into the Orkney Islands. They contain an interesting assemblage of fossil fishes of the genera *Pterichthys*, *Coccosteus*, *Cheiracanthus*, *Diplacanthus*, *Cheirolepis*, *Dipterus*, *Osteolepis*, *Diplopterus*, *Platygnathus*, etc.; also abundant crustacean cases of the genus *Estheria*, and land-plants—conifers, *Lepidodendra*, *Lycopodites*, and ferns.

Lower.—Red sandstones and conglomerates lying unconformably upon the metamorphic rocks of the Highlands. *Pteraspis* has been found in these beds near Lybster, in Caithness.

Shropshire, Herefordshire, etc.—In the section, Fig. 153, and in the descriptions of the Upper Ludlow rocks of Shropshire and Herefordshire, we found them passing up into a series of red flagstones and sandstones. In Shropshire, this series of red sandstones, with bands of impure arenaceous limestone (cornstone) and occasional beds of red conglomerate, and red and green clays or marls, lies regularly and conformably upon the Upper Ludlow rocks, and dips at a gentle angle to the south-east, so as to show a thickness of 3700 feet, when it is covered by the Carboniferous rocks of the Clee Hills. It spreads from this district to the south-west, through Hereford into Monmouth and Brecknock, where it acquires an enormous thickness—at least 10,000 feet. It forms mountains nearly 3000 feet high (one of the Brecon Vans is 2860 feet), in which the beds lie at a very gentle angle, and show but a small part of the formation. In this district cornstones seem to abound more near the centre and lower part of the formation, while beds of conglomerate occur in its upper part. Proceeding into Caermarthenshire, its lower beds are tilted up into a vertical position, along with the Upper Silurians, and in the country south of Llandeilo Fawr they lie as in the following section (Fig. 154). The lower beds are only to be separated here from the Upper Silurian by the most arbitrary line of division, founded on the gradual disappearance of all fossils as the rocks get more and more red. The uppermost red rocks, on the other hand, dip conformably beneath the escarpment of the Carboniferous limestone, and some of the yellow sandstones and shales, which appear among the uppermost red rocks, contain fragments of plants.

Between this upper and lower part there is unfortunately the

longitudinal valley of Cwm Cennen, in which no rock is to be seen; but on proceeding eastwards to the head of that valley, and crossing that of the Sawdde to the head waters of the Usk or Wysg, the intermediate rocks are met with, and appear to connect the top and bottom

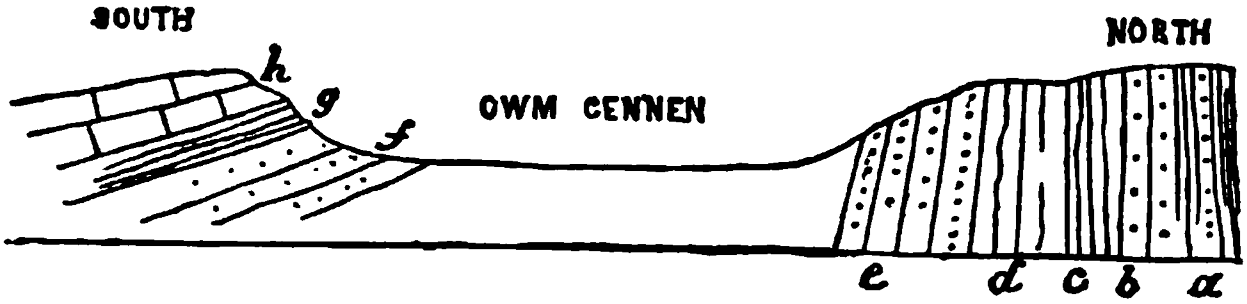


Fig. 154.

Section across Cwm Cennen, three or four miles S.W. of Llandeilo Fawr, reduced from sec. 2, sheet 3, of the horizontal sections of the Geological Survey.

Length of section, about three miles.

		Feet.
Carboniferous.	*h.* Carboniferous limestone	500
	g. Lower limestone shale	100
Old Red Sandstone.	*f.* Red and yellow sandstones	800
	A space of nearly a mile in width, in which no rock is seen.	
	e. Red sandstones and red cellular clay rock, and cornstones	1200
	d. Laminated red and grey beds	200
Upper Silurian.	*c.* Laminated grey beds (Tilestone)	450
	b. White and grey sandstone (fossiliferous)	350
	a. Laminated sandstones and shales (fossiliferous)	500

of the formation, both lithologically and by their "lie," since their angle of dip gradually increases towards the Silurian country, and decreases as gradually towards the Carboniferous. In South Wales, then, there is no apparent break in the continuity of the Old Red Sandstone, though it is difficult to explain its "position and lie" with respect to the Carboniferous rocks of Pontypool, and the Upper Silurians N.W. of Usk, without supposing an unconformability or separation there of some kind between the upper and lower part of the series.

Fossils are extremely rare in the Welsh and English Old Red Sandstone. Remains of fish of the genera *Cephalaspis* and *Pteraspis* occasionally occur in the cornstones as well as in the tilestone and Ludlow series below; also the large crustaceans *Eurypterus* and *Pterygotus*.

IRELAND.—It has been already stated that the representatives of the Wenlock and Ludlow groups can be identified by means of their fossils at the extremity of the Dingle Promontory in County Kerry. Now the rocks are there so violently disturbed that it is almost impossible to make out the details of their structure satisfactorily; but the main facts, as exhibited in the following diagram, are clear enough. This diagram is based on the data to be seen in two or three transverse sections across the peninsula and in the maps of the whole

district, so that it represents the truth, although there is no one line of country in which all the facts given in it are to be observed together.

The Croghmarhin beds, containing *Pentamerus Knightii* and other Ludlow fossils, dip south at a high angle, under a great series of red and green grits and red and purple slates, with bands of purple conglomerate, some pebbles in which contain Llandovery fossils. This great series we call the "Dingle beds." Some facts connected with

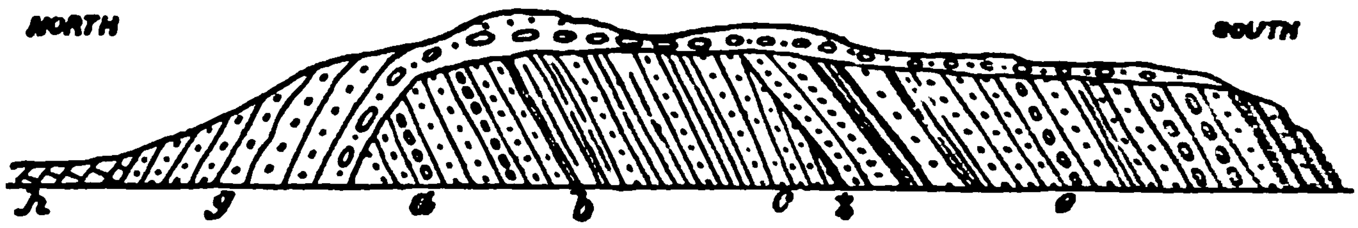


Fig. 155.

Diagrammatic section representing the relation of the Dingle beds to the rocks above and below them.

h. Carboniferous limestone.
g. Old Red Sandstone, 3000 or 4000 feet.
Unconformability.
e. Dingle beds, sandstones, slates, and conglomerates, 7000 to 10,000 feet.
* Possible unconformability.
c. Croghmarhin beds, with Ludlow fossils.
b. Ferriters Cove beds, with Wenlock fossils.
a. Smerwick beds, red and green and yellow sandstones and conglomerates, no fossils.

the general structure of the district led the author to suspect that they are not quite conformable to the rocks containing Upper Silurian fossils below them, but creep across them so as ultimately to rest on the Smerwick beds *a*. This, however, is a doubtful point, while there can be no doubt of their being above the Croghmarhin beds. The Dingle beds are clearly seen in the cliffs of the coast for several miles, dipping invariably south at an angle of 60° or thereabouts, and striking through a succession of headlands along the coast in which Ventry and Dingle Harbours lie. Mount Eagle and Brandon Mountain, the latter of which is over 3000 feet in height, are entirely composed of them. Their thickness cannot be less than 7000 or 8000 feet, and that is not their whole thickness, since their topmost beds are nowhere to be seen. The uppermost beds which are seen strike along the cliffs of the north side of Dingle Bay for several miles, and plunge to the south into the water ; and when, as the peninsula expands, they strike into the land, they are very shortly covered by another set of red sandstones and conglomerates which rest unconformably on the edges of the Dingle beds. These overlying unconformable beds, which are undoubted Old Red Sandstone, appear at first as isolated patches on the hill-tops, or as borders to the peninsula, as their beds rise from the sea ; but as we proceed towards the east or inland, they spread farther

and farther towards the centre of the peninsula, and soon arch over the tops of the hills in continuous sheets, horizontal in the centre, but dipping on either hand towards the sea, at higher and higher angles as they near the coasts. The Dingle and Silurian beds may be still seen beneath them for a short distance in the glens and valleys which have been worn down through the unconformable covering, as on the slope of Caherconreagh and in the Derrymore Glen; but as the hills gradually decline towards the east, and the Old Red Sandstone sinks even a little faster in that direction, the lower rocks become shortly quite concealed by it, and it itself dips conformably, and at a gentle angle, beneath the Carboniferous limestone both to the north and south, and round the eastern termination of the range, which is there called Slieve Mish.*

We have here, then, as in Scotland, two sets of red rocks, which might be each called the Old Red Sandstone, since they both lie between the Upper Silurian and the Carboniferous formations, but yet are clearly separated from each other by their decided unconformability, the one adhering to and forming, as it were, the upper portion of the Silurian series, the other quite separated from that, and passing up into the base of the Carboniferous rocks.

In the south of Ireland, in the counties of Kilkenny, Waterford, and Cork, we get, resting unconformably on the Lower Silurian rocks, a series of red sandstones and slates, very similar to the upper part of the red series of South Wales, and, like it, conforming to, and graduating up into, the carboniferous rocks above. In Ireland, indeed, it is harder and more affected by slaty cleavage, so that the clays of Wales take the form of clay-slates in Ireland. Both round the South Welsh coal-field and in South Ireland, the uppermost part of the group contains a number of beds of yellow and greenish sandstone and shale; the yellow sandstones being also so well developed in the north of Ireland as to lead Sir R. Griffith to give the name of the "Yellow Sandstone" to the upper part of the series. Near Goresbridge, in Kilkenny, the group commences as a very thin band, but swells out towards the south-west in Waterford and Cork to a thickness of several thousand feet. At Kiltorcan Hill, near the village of Ballyhale, in the parish of Knocktopher, County Kilkenny, are quarries in the upper yellow or greenish sandstones, from which remarkably fine fronds of a fern, nearly two feet across, have been procured—called *Cyclopteris Hibernica* by Professor E. Forbes, but since included by Professor Schimper in his genus *Palæopteris;* two other ferns, referred to *Sphenopteris*, have been described by Mr. W. H. Baily; together with plants of a genus called *Cyclostigma*, by Professor Haughton, as well as another and distinct form, the stems of which, having a fluted surface, have

* See *ante*, p. 283.

been traced downwards to its roots (Stigmaria-like) and upwards to its terminal branches, with fruit resembling Lepidodendron. This last species has been named by Professor Schimper *Sagenaria Bailyana.* There occur also fish-scales belonging to the genera *Glyptolepis* and *Coccosteus*, and conical teeth, assigned to *Dendrodus* and *Bothriolepis* by

Fossil Group No. 13.

a. Adiantites (Cyclopteris) Hibernica. b. Sagenaria Bailyana (upper portion of branch.) c. Anodonta Jukesii.

Mr. Baily, together with a large fresh-water bivalve shell called *Anodonta Jukesii* by E. Forbes, and fragments of *Eurypterus*, *Pterygotus*, and a phyllopod crustacean named by Mr. Baily *Proricaris.** The Fossil Group No. 13 gives three of these species.

The Old Red Sandstone of this part of Kilkenny is about 800 feet thick, and passes quite conformably beneath the dark shales and grey limestones of the Carboniferous series. The ferns and the *Anodon* have been found also near Clonmel and near Cork; and fragments of the plants always occur in the upper part of the Old Red Sandstone

* See Explanation of Sheets 147 and 157 of the *Geological Survey of Ireland.*

throughout the south of Ireland. At Tallow Bridge, in Waterford, very large stems are exposed.*

The occurrence of these fossils in beds just a little below the base of the undoubted Carboniferous limestone, aids us in fixing the place of the corresponding beds in Scotland, in which similar fish and plants occur. The occurrence of the large fresh-water shell, so like the Anodon of our own lakes, raises a strong presumption in favour of the fresh-water character of the fish, and thus lends support to Mr. Godwin Austen's idea that the Old Red Sandstone is a fresh-water formation.

Volcanic Rocks of Old Red Sandstone Period in Britain.

Reference has already been made to the abundant intercalation of volcanic rocks in the Old Red Sandstone of the southern half of Scotland. They occur in each of the three subdivisions of the system, but most abundantly in the lower. In the chains of the Sidlaw, Ochil, and Pentland Hills, and the ground stretching south-westwards into Ayrshire, the lower Old Red Sandstone consists to a large extent of interbedded porphyrites and tuffs, with ashy sandstones and trappean conglomerates. The middle Old Red Sandstone of Ayrshire likewise contains some thick sheets of interbedded porphyrite. At the top of the upper division of Berwickshire some trap-tuff occurs.

In Ireland, among the wilds of Kerry, numerous bands of trap-tuff —one of them 500 to 600 feet in thickness—are interstratified with the ordinary strata.†

No volcanic rocks appear to have been yet detected in association with the Old Red Sandstone of England or of Wales.

* See Explanation of Sheets 176 and 177 of the *Geological Survey of Ireland.*

† *Mem. Geol. Surv. Ireland.* Explanations to Sheets 153 and 184.

CHAPTER XXXIII.

CARBONIFEROUS PERIOD.

The peculiar kind of rock which we call coal is not strictly confined to any part of the series of stratified rocks, but occurs here and there in different parts of it, from the lowest to the highest. Beds of good coal, however, are much more abundant in one particular part of the series than in any other part. This is especially the case in Europe and America. The group of rocks, therefore (or system of formations), in which these beds of coal occur, is called the Carboniferous system, and the period of time during which that system was being deposited may hence be called the Carboniferous period.

England.

The Carboniferous system as developed in the British Islands presents several distinct types of formations, which will be best understood from a description of the different districts in which they occur.

South Wales.—The section given in Fig. 154, and the one which follows (Fig. 156) will explain the structure of the great South Welsh coal-field, and the neighbouring ones of the Forest of Dean and Bristol.

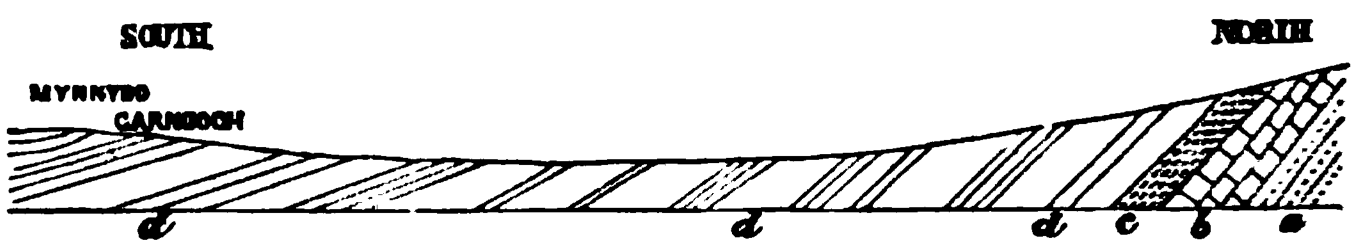


Fig. 156.

Diagrammatic section across the northern edge of the coal-field of S. Wales.

This is deduced (omitting the flexures of the beds and other details) from Sheet 8 of the horizontal sections of the Geological Survey, drawn across the centre of the field between Swansea and Llandeilo Fawr, by Sir W. Logan.

	Feet.
d. Coal-measures, with 50 beds of coal varying from 6 inches to 6 feet	9600
c. Farewell rock (Millstone grit)	400
b. Carboniferous limestone	600
a. Old Red Sandstone.	

In Fig. 156 no notice is taken of the shaly base of the Carboniferous limestone, which nevertheless exists as drawn by Professor Phillips in section Fig. 154, and is a constant member of the series throughout the district, as it is over the south of Ireland.* The

* See also sections in *Mem. Geol. Survey*, vol. i.

general description of the formation in this district may be given as follows, assigning the maximum thickness to each group :—

	Feet.
4. Coal-measures, Upper series	3400
,, Pennant Grit series	3246
,, Lower series	450 to 850
3. Millstone Grit, or Farewell rock	1000
2. Carboniferous Limestone	500 to 1500
1. Lower Limestone Shale	200
Old Red Sandstone.	

1. The *Lower Limestone Shale* consists of dark earthy shales, occasionally interstratified with yellowish sandstones below, and always with thin flaggy limestones in its upper part. It seems, therefore, to graduate downwards into the top of the Old Red Sandstone, as well as upwards into the Carboniferous limestone. According to Mr. Salter, it contains precisely the same fossils as are found in it in Ireland.

2. *Carboniferous Limestone.*—A series of compact limestones, thick and thin bedded, of various shades of grey and red, sometimes, as near Bristol, interstratified with brown, grey, and red shales below, and with shales and sandstones (often red) in the upper portion. Thickness 500 to 1500 feet.

3. *Millstone Grit or Farewell rock.*—A series of sandstones, hard, quartzose, white or grey, and near Bristol red. Maximum thickness about 1000 feet.

4. *Coal-measures.*—An enormous series of alternations of many hundred beds of shales, sandstones, and coals, the latter varying from one inch to seven or eight feet in thickness, twenty-five of them being more than two feet. The Pennant sandstones belong typically to the South Welsh basin.* They occupy the central and lower portions of the series, and contain 15 coal-seams. The coal under the western portion of the basin is anthracitic; under the central, semi-bituminous, producing the valuable "steam coal" of commerce; and under the eastern portion, bituminous. These changes take place gradually over the whole area. The total thickness of the whole Coal-measure group is not less than 7000 feet, and is believed in some places to be even as much as 12,000 feet.†

Near **Bristol** the Coal-measures are thinner, and are divisible into three sub-groups, having a central band of hard sandstones called Pennant.

	Feet.
c. Upper Coal-measures, with 10 coals	1800
b. Pennant series, with 5 coals	1725
a. Lower Coal-measures, with 36 coals	1565
Total Coal-measure series	5090

* See Logan, *Geol. Trans.*, 2d series, vol. vi. p. 491.

† *Mem. Geol. Survey*, vol. i. p. 202.

This central band of sandstones is traceable also in South Wales, by means of a hard quartzose sandstone called Cockshoot rock. The structure of the lower groups is also peculiar; a section of them is given in detail from the measurements of Mr. D. Williams.* If we take the first ten divisions of that section for Millstone grit, and put the others into groups, they would be as follows:—

	Ft.	In.
Millstone Grit, or Yoredale Beds (partly red sandstone)	975	9
Upper Limestone (the first 370 feet containing many red sandstones interstratified with the limestones)	576	0
Black and brown argillaceous limestones and shales	477	0
Lower Limestone	766	4
Lower Limestone shale	411	0
Yellow sandstone series	293	10
	3499	11

In the **Forest of Dean** coalfield, the thicknesses given above are diminished to about one-third, or

	Feet.
Coal-measures, with 31 coals, generally thin	2400
Millstone Grit	455
Carboniferous Limestone	480
Lower Limestone shale†	165

Midland Counties.—In the centre of England we get the coalfields of Leicestershire, Warwickshire, South Staffordshire, and Coalbrokedale, with other smaller ones near Shrewsbury, which differ from those both north and south of them in being defective at their base. They consist principally of Coal-measures only, resting on Cambrian or Silurian rocks. Carboniferous Limestone sets in again at the northern sides of the Leicestershire and Coalbrokedale coalfields, and the Old Red Sandstone sets in to the south of the latter, and underlies the coalfield of the Forest of Wyre, letting in a thin portion of Carboniferous Limestone about the small coalfield of the Brown Clee Hill; but the Coal-measures overlap these as they die out from the north and the south respectively, and repose indiscriminately on any lower rocks there may be.

It seems as if a narrow rocky island or chain of islands had stretched east and west from North Wales and Shropshire, across the centre of what is now England, during the early part of the Carboniferous period, so that while the Carboniferous Limestone was being formed in the seas to the north and south, it died out as it approached this ridge of dry land. South of the Dudley coalfield this ridge seems to have formed the margin of the Coal-measures themselves, as it has been recently proved that the Main Coal terminates in the direction of

* *Mem. Geol. Survey*, vol. i.

† *Ibid.* pp. 129, 203, 206.

the Clent and Lickey Hills, against the Silurian rocks. At the still earlier period of the deposition of the Old Red Sandstone, this barrier seems to have been wider and more persistent, and to have extended through what is now Ireland, since the Old Red Sandstone dies away as we proceed from the south to the centre of both countries, and does not again appear, except as detached patches, until we reach the centre of Scotland. During the latter part of the Carboniferous period, however, the barrier was depressed, and the water in which the Coal-measures were deposited extended over it, so that this upper part of the formation was spread continuously across from the regions of the south to those of the north.*

The North of England and Wales.—To the north of the district just mentioned, the Carboniferous formation is magnificently developed. In North Wales and Cumberland, the base of the series may be seen resting chiefly on Upper and Lower Silurian rocks, with scraps and patches of Old Red Sandstone appearing here and there in the hollows of those rocks below the limestone. The Carboniferous limestone is generally about 1000 or 1500 feet in thickness, sometimes much more, chiefly pure compact limestone, but taking in here and there beds of black shale. It is covered by beds of shale, with thick beds of sandstone graduating up into a series of sandstones and shales, containing beds of coal. These form the groups known as the Yoredale Beds, Millstone Grit, and the Coal-measures.

Pennine Chain, from Derbyshire to the Cheviots.—There rises gradually from the central plains of England a broad ridge of wild moorlands, the summits of which are often 2000 feet above the sea. This is formed of a broad anticlinal curve, a good deal broken by large faults along its north-west flank towards Westmoreland and Cumberland, and along its western margin into Staffordshire. On the opposite side, throughout Yorkshire and Derbyshire, the beds are much less disturbed, and generally dip at a moderate angle beneath the coal-measures.

In Derbyshire the Carboniferous limestone rises to the surface about the central portion of the anticlinal curve, and is deeply cut into by picturesque valleys, though the base of the series is nowhere exposed. As the ridge sinks towards the south, the beds are overlapped and concealed by the New Red Sandstone, but on each flank of the ridge a section is shown more or less closely identical with that given in Fig. 157. Mr. E. Hull has recently shown that the north and south axis of this range is referable to the period intervening between the Permian and Trias, while the east and west flexures are referable to the period between the close of the Carboniferous and commencement of the Permian periods.†

* See *ante*, p. 236.

† "On the Relative Ages of Physical Features, etc." *Quart. Journ. Geol. Soc. London*, vol. xxiv. p. 323.

The Coal-measures mentioned in the following section extend from Nottingham to Leeds, on the east side of the anticlinal, while on the

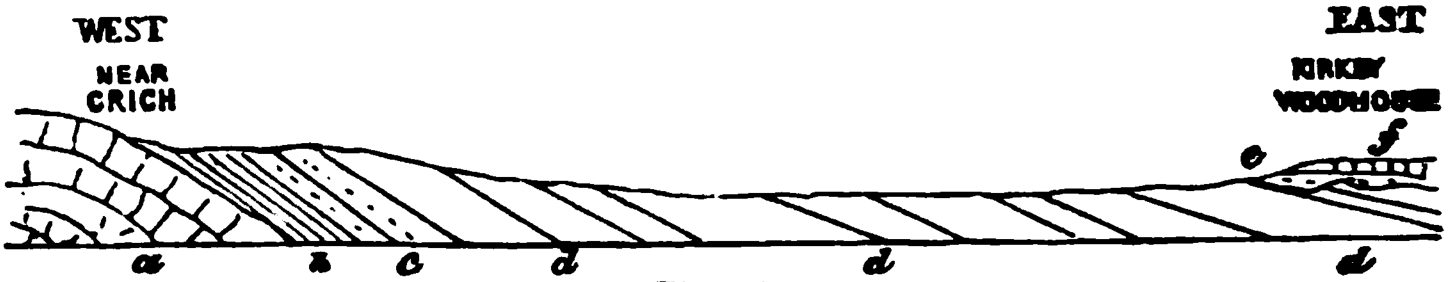


Fig. 157.

Diagrammatic section across a part of the Derbyshire coalfield.

Reduced from Sheet 60 of the Horizontal Sections of the Geological Survey (drawn by W. T. Aveline and E. Hull), omitting flexures and faults.

				Feet.
Permian Rocks.	*f.* Magnesian Limestone.			
	e. Rothliegende (occasional).			
Carboniferous Rocks.	*d.* Coal measures.	Beds above the Ganister series	. . . . . .	2100
		Ganister coals and sandstones	. . . . . .	1000
		Beds below the Ganister	. . . .	600
	c. Millstone Grit.	Grits, sandstones, and shales, with thin coals	. .	350
	b. Upper Limestone shale (black shales)		. . . .	250
	a. Carboniferous Limestone (about)		. . . .	1000
				5300

west side they form the coalfields of North Staffordshire, Cheshire, and Lancashire. In these coalfields there is a much greater thickness of Coal-measures, and also of Millstone grit and Upper Limestone shale, than on the eastern side. Mr. Hull gives the following as the section of North Staffordshire in the Horizontal Sections of the Geological Survey, Sheets 42 and 55 :—

	Feet.
Permian rocks	600
4. Coal-measures (in three subdivisions)	5000
3. Millstone Grit	4000
2. Yoredale Rocks	2300
1. Carboniferous Limestone . . . . more than	4000
	15,300

The Lancashire district is stated by Mr. Hull to show the following beds :—

	Feet.
New Red Sandstone	4000
Permian	500
3. Coal-measures (in three subdivisions)	7200
2. Millstone Grit, from 3500 to	5500
1. Yoredale Rocks, from 2000 to	4500

However extraordinary the thickness of the Lower Carboniferous beds in this district may appear, there is no doubt of the fact, as the

results have been confirmed by many independent sections measured across the Pendle range of hills, where the beds rise to the northward for many miles with wonderful regularity, and at high angles. In truth, the Carboniferous series overlying the Limestone attains in this part of England a development nowhere surpassed; and commences to thin away towards the south-east into Leicestershire and Warwickshire; so that a combined series of beds which originally attained in North Lancashire (near Burnley) a thickness of more than 18,000 feet, in the former counties is represented by about 3000 feet of strata.*

At Dukinfield, near Manchester, a single shaft, sunk by Mr. Astley at a cost of £100,000, has a depth of 2151 feet, passing through 30 different beds of coal, having an aggregate thickness of 105 feet. Twenty-two of these coals are of workable quality and thickness.† Rose Bridge Colliery, near Wigan, is even deeper.

In Nottinghamshire, the Duke of Newcastle has lately sunk a deep shaft through the Permian rocks into the Coal-measures, of which a detailed account is given by Messrs. Lancaster and Wright in the *Quarterly Journal of the Geological Society, London*, vol. xvi. p. 138. After passing through about 200 feet of Permian rocks, they sank through 222 sets of beds of sandstone, shale, and coal, with a total thickness of 1300 feet, down to the Top Hard or Barnsley Coal, which was not quite 4 feet thick, and then sank and bored below that to a total depth of 1642 feet from the surface. The "Top Hard" of the Derbyshire coalfield is believed to be the same bed as the "Barnsley coal" of the Yorkshire coalfield, and it has a thickness of upwards of 2000 feet of Coal-measures below it in each place.

Millstone Grit and Yoredale Series of North Staffordshire, Derbyshire, Lancashire, and Yorkshire.—It has recently been found, by the officers of the Geological Survey, that these beds, which are interposed between the Lower Coal-measures and the Carboniferous Limestone, are divisible into the following subdivisions, which have been traced over a large tract of the Pennine chain and adjoining districts.

Millstone Grit Series.	First Grit or Rough Rock. Shales. Second Grit, or Haslingden Flags. Shales. Third Grit (often in two beds). Shales. Fourth, or Kinder Scout Grit (often in two or more beds).

* "On the thickness of the Carboniferous Rocks of the Pendle Range, etc.," by E. Hull. *Quart. Journ. Geol. Soc.*, vol. xxiv. p. 319.

† The lowest coal reached is called the "Black mine," and is 4 ft. 8 in. thick, and it was calculated as able to supply 500 tons daily for thirty years, the estate being 1263 acres. The shaft is 12 ft. 6 in. diameter, but expands near the bottom to 19 ft. 2 in. It is lined with bricks 9 in. thick, with rings of stone at intervals of 8 yards.—*Times*, 31st *July* 1858.

Yoredale Series . .	Shales. Yoredale Grit. Shales. Yoredale Sandstone. Black Shales with thin Limestones.

As we trace the Millstone Grit and Upper Limestone shale from the neighbourhood of Matlock or Buxton to the north, they each seem to become more complicated, and the upper part of the Carboniferous Limestone, both to the west and north, becomes split up by beds of shale, so that in Yorkshire there is a great series of alternations below the Coal-measures, consisting of shales and sandstones with thin coals in the part called Millstone Grit; and shales and sandstones with thin limestones in the part called Upper Limestone Shale. In Yorkshire this Upper Limestone shale and top of the Carboniferous limestone is called the Yoredale series by Professor Phillips, and the thick limestones below are called the Scaur Limestone.

The lie of the rocks too becomes more irregular a little north of Leeds, the anticlinal ridge expanding, and its flanks being thrown off more irregularly, so as not to bring in the Coal-measures over them, (except in one small patch) on either the east or west for a space of sixty miles.* On the west side, indeed, the great Cross Fell or Pennine and Craven faults, and other large dislocations, utterly disturb the regularity of the lie of the rocks up to the Cheviot Hills; but towards the east they dip gently beneath the large Durham and Newcastle coalfield, while the outlying coalfield of Whitehaven comes in on the coast of Cumberland on the west. A section drawn across the country from the valley of the Eden to the mouth of the Tyne, would exhibit the following series of rocks:—

	Feet.
4. Coal-measures	more than 2000
3. Millstone Grit	414
2. Yoredale series	540
1. Great or Scaur Limestone group .	more than 1119

1. The Great or Scaur limestone, as described by Foster in Teesdale, consists of ten sets of beds of limestone from 7 to 130 feet in thickness, separated by as many sets of shale and sandstone varying from 12 to 240 feet thick, the total thickness of the whole being 1119 feet, with the bottom not seen.†

2. The Yoredale series contains nine sets of limestone from 2 to 30 feet thick, with as many alternations of shale and sandstone, from 17 to 70 feet thick, with occasional beds of coal, the whole being 540 feet thick.

* North of Leeds the Carboniferous rocks are thrown into great folds, ranging nearly E. and W. See Hull. *Quart. Journ. Geol. Soc.*, vol. xxiv. p. 323.

† Phillips' *Manual of Geology*, p. 163.

3. The Millstone grit here contains one central band of limestone, called Feltop limestone, between alternations of sandstone, shale with ironstone, and coal, having a total of 414 feet.

4. The Coal-measures of the Tyne district (Newcastle, etc.) are about 2000 feet in thickness, containing about 600 separate beds (or measures), and a total of about 60 feet of coal. The coal lies in many beds, two of which are 6 feet in thickness, and three others 3 feet or more. A little farther north, about Berwick-on-Tweed, good beds of coal are worked down near the very base of the series in the group described above as the Great Scaur Limestone group.

Scotland.

The Carboniferous system is well developed along the great midland valley of Scotland from the shores of the Firth of Clyde to the mouth of the Firth of Forth. The lower part of the system exhibits a still farther change in the same direction as that which takes place in the north of England. Instead of a great base of massive limestones, the lower formations consist mainly of sandstones and shales, with comparatively few and thin limestone bands. We may infer that the early Carboniferous land of our area lay somewhere to the north, while over the greater part of central and northern England there was sea. Later on in the Carboniferous period, however, when the Coal-measures were deposited, a greater uniformity of conditions seems to have obtained, for, except in diminished thickness, the Scottish Coal-measures do not differ markedly from those of the sister kingdom.

Recent examinations by the Geological Survey have shown that the Carboniferous rocks of Scotland are capable of convenient grouping into the following subdivisions :—

4. Coal-measures.	*f.* Red sandstones and clays. *e.* White and grey sandstones, shales, fireclays, coals, and ironstones.
3. Moor-rock or Millstone Grit.	*d.* White and grey sandstones and coarse grits, with some thin coal seams.
2. Carboniferous Limestone Series.	*c.* Sandstones, shales, coals, ironstones, and bands of Encrinite limestone.
1. Calciferous Sandstone Series.	*b.* White and grey sandstones, black and blue shales, cement-stones, cyprid-limestones, and occasional coal-seams. *a.* Red and purple sandstones, conglomerates and cornstones.

1. Calciferous Sandstone Series.—This basement series consists of two groups. The lower (*a*) is formed of dull red, reddish grey and purple sandstones, sandy shales, conglomerates, and occasional seams of cornstone. *Lepidodendron*, *Calamites*, and other plants, are occasionally found in these beds. In the counties of Edinburgh, Lanark, Peebles, Ayrshire, Renfrewshire, and Dumbartonshire, these red sandstones are seen resting unconformably on middle and lower Old Red Sandstone

and Silurian rocks. In Haddingtonshire and Berwickshire they are less developed, but there they pass down conformably into upper Old Red Sandstone, from which they are on the whole distinguished by a difference of tint. The upper group (*b*) is less persistent, or at least subject to much more decided local variations, in some places being entirely absent, in others swelling out to a thickness of several hundred feet. It consists of white and grey sandstones, blue and black shales, (some of which are highly bituminous, and are now extensively used for making paraffin oil), limestones full of cyprids, cornstones, and a few occasional coal-seams. One of the limestones is the well-known seam of Burdie House, near Edinburgh, from which *Megalichthys* and other Carboniferous fishes were first described.*

2. Carboniferous Limestone Series.—This division of the system usually consists of two or three lower limestone bands associated with sandstones, shales, and coal-seams, a thick middle group of coal-bearing strata, with some valuable clay ironstones, but without limestones, and an upper group containing two or three comparatively thin but widely spread bands of limestone. The limestones are all marine, being full of encrinites, corals, brachiopods, etc. They usually do not exceed ten or twelve feet in the thickness of each band, but sometimes swell out locally to three or four times that thickness. One of the lower limestones is frequently found resting directly on a seam of coal.

In the Carboniferous limestone series of Linlithgowshire and Fife there is an abundant intermingling of contemporaneous volcanic rocks which continued to be thrown out in that region intermittently from the time of the deposition of the Calciferous sandstones, onward through nearly the whole of the period occupied by the accumulation of the Carboniferous limestone series.†

3. Millstone Grit.—In Edinburghshire, Fife, and Lanarkshire, there occurs a thick series of coarse sandstones, locally known in some places as *moor-rock*, lying above the Carboniferous limestone series and below the Upper coal-bearing series or true coal-measures. These sandstones are regarded as probably representing the English Millstone grit. In Ayrshire they are so diminished as not to be separable into any definite group, the Carboniferous limestone series and coal-measures appearing to shade into each other.

4. Coal-measures.—Above the Moor-rock, and conformably interlaced with it, comes an upper series of strata, divisible into two groups. Of

* See Hibbert, *Trans. Roy. Soc. Edin.*, vol. xiii. For further information regarding the Calciferous sandstone series, see MacLaren's *Geology of Fife and the Lothians.* Also the *Geological Survey Memoirs*, Explanation of Sheets 14, 15, 32, 33, and 34.

† For information regarding the Scottish Carboniferous limestone series, consult the *Geology of the Neighbourhood of Edinburgh* (*Memoirs of the Geological Survey*); MacLaren's *Fife and the Lothians*; J. Young on Campsie Limestones, in *Trans. Geol. Soc. Glasgow*, vol. i.

these the lower (*e*) consists of grey and white sandstones, shales, and fireclays, with coal-seams and clay-ironstones; the upper (*f*) is made up chiefly of red sandstones and clays without coal-seams. This upper group in Ayrshire contains a seam of limestone with *Spirorbis*. Although this red sandstone series appears in most places as if conformably overlying the coal-bearing measures below, in parts of Ayrshire it overlaps these so as to rest directly upon a low part of the Carboniferous limestone series.*

Ireland.

In no European country is the lower portion of the Carboniferous formation better developed or more clearly seen than in Ireland.

Carboniferous Slate and Coomhola Grits.—In the preceding chapter mention was made of the Old Red Sandstone which sets in, in the counties of Kilkenny and Wexford, as a very thin deposit, but swells rapidly out in Waterford, and acquires enormous bulk in Cork and Kerry. In the two latter counties the Old Red Sandstone consists of a vast series of green, brown, and purple gritstones, interstratified with green and purple slates. This series is covered quite conformably, as may be seen in the country round Bantry Bay, and thence by Skibbereen to Kinsale and Cork Harbour, by other grits and slates, which

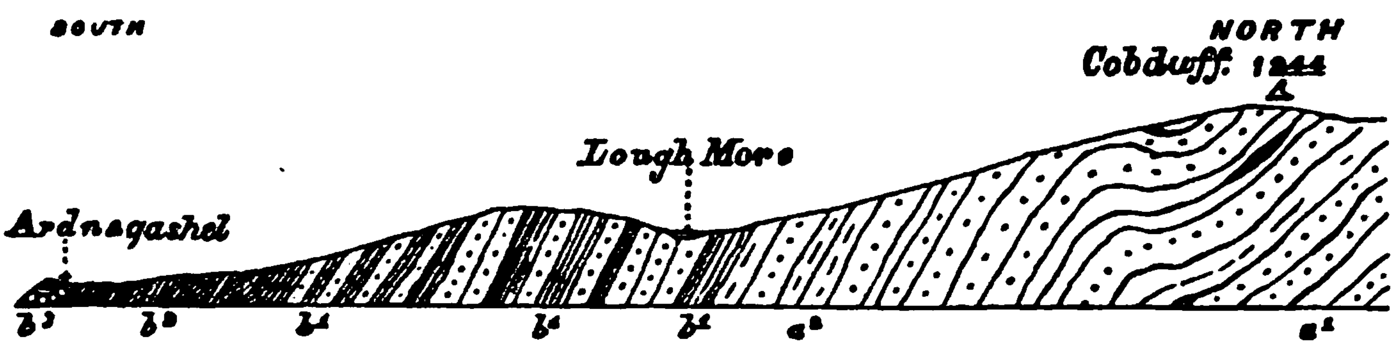


Fig. 158.

Section about 2½ miles long, from S. to N. across the hills on the east side of Glengariff Harbour, and between it and the Glen of Coomhola.

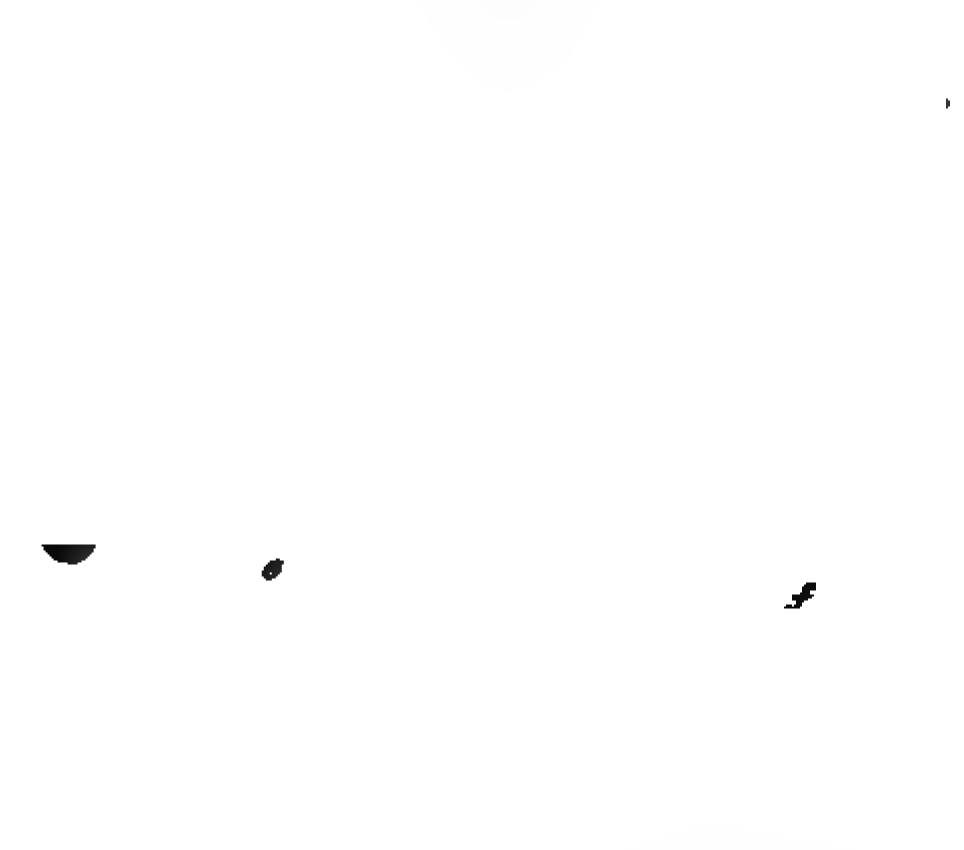
b^3. Black slate with calcareous bands, full of fossils.		
b^2. Black and grey slate, with few fossils.		Carboniferous Slate.
b^1. Grey and greenish grey grits, with interstratified black and grey slates, with marine shells and some plants (Coomhola grits).		
a^2. Grey and greenish-grey grits, interstratified with green, liver-coloured, and purple slates, containing fragments of plants, the beds getting redder below, and plants disappearing. Cornstones occasionally.		Old Red Sandstone.
a^1. Green and purple massive grits (Glengariff grits), and thin bands of purple slate. Cornstones occasionally.		

differ from those below chiefly in the entire absence of red colour, and the predominance of grey passing into black. This upper series has

* In addition to the papers already cited, further information on the Scottish Carboniferous rocks may be obtained from Mr. Ralph Moore's *Section of the Lanarkshire Coalfield*.

been called by Sir R. Griffith, Carboniferous slate. In Bantry Bay there is not much change in the appearance of the sandstones and gritstones about the junction of the Old Red Sandstone and Carboniferous slate, so that the boundary between them can only be at first determined by noting the change in the colour of the slate bands that lie between the grits.

Numerous sections might be drawn in many parts of the county Cork to show the relations of these rocks, but the one in Fig. 158 is taken in a part of the district frequently visited, and interesting for its picturesque beauty as well as its geology. It explains the lie and position of the beds on the east side of Glengariff Harbour, in Bantry Bay. About Glengariff and about Bear Island, and thence to Dursey Island, and also along the south side of Kenmare Bay, from Kilmacalloge to Killcatherine, these beds are admirably shown. The groups called b^3 and b^2 in the section Fig. 158 cannot be less than 2000 feet, and the group called b^1 (the Coomhola grit group) must be at least 3000 feet thick, so that we may state the Carboniferous slate of County Cork to have a maximum thickness of at least 5000 feet.



Fossil Group No. 14.—Carboniferous Slate Fossils.

a. Spirifera cuspidata.
b. Rhynchonella pleurodon.
c. Avicula Damnoniensis.
d. Modiola Macadami.
e. Cucullæa Hardingii.
f. Curtonotus elegans.

Characteristic Fossils.—The calcareous bands called b^3 have numerous fossils, among which are the following :—

Actinozoa . .	Cyathophyllum (Petraia) pleuri-radialis	Phill. Pal. foss., t. 2.
Polyzoa . .	Fenestella antiqua . .	Phill. Pal. foss., t. 12.
Brachiopoda .	Athyris planosulcata . .	Phill. G. Y., t. 10, fig. 15.
	——— lamellosa . . .	Phill. G. Y., t. 10, fig. 21.
	Streptorhynchus crenistria .	Phill. G. Y., t. 9, figs. 5 and 6.
	Orthis Michelini . . .	Phill. G. Y., t. 11, fig. 3.
	——— resupinata . . .	*Ibid.* fig. 1.
	Producta scabricula . .	*Ibid.* t. 8, fig. 2.
	Rhynchonella pleurodon . .	Foss. gr. 14, *b.*
	Spirifera cuspidata . .	Foss. gr. 14, *a.*
	——— disjuncta (Verneuillii)	Phill. Pal. foss., t. 29 and 30.
	——— lineata . . .	Phill. G. Y., t. 10, figs. 17, 20.
	——— striata . . .	Foss. gr. 16, *e.*
Conchifera .	Avicula Damnoniensis . .	Foss. gr. 14, *c.*
	Modiola Macadami . .	Foss. gr. 14, *d.*
	Nucula, *species.*	
Echinodermata	Actinocrinus	Phill. G. Y.
	Archæocidaris (plates of) .	M'Coy. Carb. foss.
	Platycrinus	Foss. gr. 18, *a.*
	Poteriocrinus . . .	Phill. G. Y.
	Rhodocrinus	*Ibid.*
Crustacea . .	Phillipsia pustulata . .	Foss. gr. 18, *d.*
	Leperditia sub-recta and L. Scotoburdigalensis.	

In the group b^1, or the Çoomhola Grit, part of the Carboniferous Slate, the following fossils have been found :—

Plants . . .	Stem of "Knorria" (probably portions of Cyclostigma) and other plants identical with those in the Old Red Sandstone below.	
Brachiopoda .	Almost all those mentioned above, the Rhynchonella pleurodon and Spirifera cuspidata and disjuncta most abundantly, with the addition of a large Lingula.	
Conchifera .	Avicula Damnoniensis . .	Foss. gr. 14, *c.*
	Aviculopecten, *species* . .	M'Coy, Carb. foss.
	Cucullæa Hardingii . .	Foss. gr. 14, *e.*
	——— trapezium . .	Phill. Pal. foss., t. 19.
	Curtonotus elegans . .	Foss. gr. 14, *f.*
	Dolabra securiformis . .	M'Coy, Carb. foss., t. 11.
	Sanguinolites plicatus . .	*Ibid.*, t. 10.
	Modiola Macadami . .	Foss. gr. 14, *d.*
	Myalina, *species.*	
	Mytilus, *species.*	
	Nucula, *large species.*	
Pteropoda . .	Bellerophon striatus . .	Phil. Pal. foss., t. 40.
	——— rounded species, sharply keeled species, and trilobed species.	
Cephalopoda .	Orthoceras, *species.**	

* See "Notes on Classification of Dev. and Car. Rocks of S. of Ireland, by J. W. Salter and J. B. Jukes, *Journ. Dub. Geol. Soc.*, vol. vii. ; and Explanation of Sheets 192, 197, and 198, Geological Survey of Ireland.

This Coomhola grit series is clearly identical with the Marwood Sandstone group of Devonshire (*ib.*), but in the south of Ireland its relation to a vast thickness of Old Red Sandstone below it, places it, in accordance with the palæontological evidence, as clearly in the Carboniferous group, and forming the base of the great Carboniferous series. It is remarkable that the boundary between it and the Old Red Sandstone below, as drawn from lithological characters and chiefly the mere colours of the rock, is in harmony with the palæontological character of the occurrence of *marine shells*. No undoubtedly marine remains are to be found in the red rocks, but as soon as the red tints disappear, we get brachiopoda and conchifera of marine characters.

If the Coomhola grits be classed with the Carboniferous series, the so-called Upper Devonian of Devonshire and the Rhine (the Marwood sandstones and the Spirifera Verneuillii schists, etc.), must also be called Carboniferous.

There is, however, something very noteworthy in the mode of occurrence of the Carboniferous slate (including the Coomhola grits) in the south-west of Ireland, which may, perhaps, eventually turn out to be in harmony with a classification which should make them a distinct sub-group in combination with the upper part of the Old Red Sandstone. If we draw a parallel of latitude through the towns of Kenmare, Macroom, and Cork, the great development of Carboniferous slate lies wholly south of that line. If we examine the neighbourhood of the city of Cork itself, we find the Old Red Sandstone with plants in its upper beds, and a very short distance above that we get solid Carboniferous limestone, with some black shales or slates between the two, but not more than 200 or 300 feet in thickness. Passing southwards to the mouth of the harbour by Monkstown or Queenstown, and then by Carrigaline and Coolmore, these intermediate black slates or shales thicken to 2000 or 3000 feet, still having the Old Red Sandstone below and the Carboniferous limestone above ; but going still farther south by Ringabella to Kinsale, the dark grey slates and grey grits thicken rapidly to 5000 or 6000 feet, and are nowhere covered by any part of the Carboniferous limestone, though they show here and there highly calcareous bands. The whole of the rocks are thrown into numerous anticlinal and synclinal curves, over many interrupted axes which strike very steadily from E.N.E. to W.S.W.; and the headlands and bays along the south coast of Cork exhibit numerous transverse sections across the beds, so that no mistake can be made respecting the facts. On tracing the beds round into Bantry Bay, across the anticlinal ridges of Old Red Sandstone that form Cape Clear, the Mizenhead, and Sheep's Head, we find the uppermost beds at the head of Bantry Bay becoming actual limestone, as if the Carboniferous limestone had only just been removed from them. Following them again over the anticlinal ridge that ends in Dursey Island into Kenmare Bay, we again find the Carboniferous slate in the hollow of the synclinal,* as far as Sneem and Clonee. Beyond these points, however, the Old Red Sandstone beds, which dip beneath the waters of the bay from each side, seem to close more together, and exclude the Carboniferous slate, and when the head of the bay is reached, the flat land is composed of solid limestone, with a thickness of not more than 100 feet of black shales and grits between the base of the Carboniferous limestone and the top of the Old Red Sandstone. The section, then, is like that shown in Fig. 154, where the Lower Limestone shale *g*, just 100 feet thick, is interposed between the top of the Old Red Sandstone *f*, and the Carboniferous limestone *h*. Kenmare is not more than ten miles from Glengariff

* The headlands of the south-west of Ireland, from Kerry Head to Cape Clear, are all formed of anticlinal ridges of Old Red Sandstone, while the indentations of Tralee Bay, Dingle Bay, and Kenmare, Bantry, Dunmanus, and Roaring Water Bays, have all been worn in the more easily destructible Carboniferous rocks which lie in the synclinal troughs between the anticlinals.

in a direct line, so that within that distance the rocks next above the top of the Old Red Sandstone vary, as is shown in the two sections, Figs. 154 and 158, and that without any appearance of discordance or interruption, but apparently by the gradual intercalation towards the south of a series of beds 5000 feet thick, which are entirely wanting over all the country to the northward. The little group of calcareous bands, called b^3 in section Fig. 158, resembles the small group of shales that occur beneath the limestone at Kenmare. The two sets of beds are probably the same, and form the Lower Limestone shale presently to be described—the Carboniferous slate and Coomhola grits coming in below as a distinct sub-group between the Lower Limestone shale and the Old Red Sandstone.

If, after examining the Carboniferous slate, we proceed northwards through Ireland, surveying the Carboniferous rocks right and left as we proceed, we shall find that they consist at first of two groups only—viz., the Carboniferous limestone below, and the Coal-measures above.

Carboniferous Limestone.—This formation has a total maximum thickness of about 3000 feet, varying, however, in different places, especially where it rests unconformably upon an irregular surface of lower rocks. Where its base is fully developed, it is always found to consist of beds of black shale, which we may call the *Lower Limestone shale*, generally about 150 feet thick, sometimes, perhaps, not more than 20, sometimes as much as 300. This, in the absence of the Carboniferous Slate, rests directly on the Old Red Sandstone, and seems even to graduate into it, the dark shales alternating with beds of yellow sandstone below, and with thin courses of limestone above. In such places there seems to be a perfect blending and continuity between the Old Red Sandstone and the Carboniferous Limestone, the Lower Limestone shale forming what would be called the passage beds, notwithstanding which there is a gap which is elsewhere filled by a deposit of at least 5000 feet thick between the two. The Lower Limestone shale has generally a peculiar assemblage of fossils, formed of a few species that range through the limestone, but are nowhere found in such especial abundance as in this lower part of it, from which other species elsewhere abundant are absent. These are the species mentioned at p. 587 as characteristic of the group b^3.

The Carboniferous Limestone of the south of Ireland is perhaps one of the largest aggregates of beds of limestone to be seen anywhere in the world. The most usual character is a grey fine-grained or compact limestone, sometimes dark, sometimes light, sometimes mottled, with occasional red streaks and bands in some of the beds. In some places it contains beds of black shale, and becomes earthy in its middle portion, and sometimes the whole of it, except the lower part, puts on this shaly and earthy character. This middle earthy and shaly part has been called Calp, from a local term, signifying "black shale." Black chert is often developed in the limestone, rows of nodules and seams

of it appearing in great abundance, sometimes in one part and sometimes in another.

This formation in the south of Ireland usually forms low gently undulating ground, and its beds are seen only in short sections or in scattered quarries. This induced me for some time to doubt whether the real thickness was so great as appeared from these isolated indications, until, in the course of the Geological Survey, we had examined the hills of Burren in County Clare, on the one side, and those of Queen's County, on the other. In Burren, especially, the upper part of the limestone is magnificently exposed. A range of hills, rather more than 1000 feet in height, sweeps for about 20 miles along the south side of Galway Bay. They are formed entirely of bare rock from the sea-level to the hill-tops, the only soil being found in crevices of the rock, or in patches in the hollows of the valleys. This rock is all limestone, in regular beds, which dip gently to the south, at an angle of $1\frac{1}{2}°$ only,* and counting from the lowest bed that rises out on the sea-shore, to the uppermost, which caps the summit of the hills three or four miles to the southward, there must be a thickness of at least 1600 or 1700 feet of solid limestone shown here. The beds can be perfectly traced round the promontories of the hills, and up the recesses of the valleys, through a winding line, the extremities of which are fully 20 miles apart, and throughout that distance Mr. Foot informed me that there is not a trace of a fault or disturbance, or even an undulation in the beds. Terraces of 20 yards in breadth have been worn here and there on the top of some particular bed, and may be walked along for many miles round the sides of the hills and valleys, which resemble great stairs, or vast amphitheatres. They are not, however, very easy to traverse, since the rocks are so cut by several systems of joints, and those joints are so worn and opened by the action of the weather, that each exposed bed is cut into blocks by deep fissures, and the uppermost blocks are often loose and tottering, and worn into rough knobs and holes by the mechanical and chemical action of the weather.† Throughout the thickness of 1600 feet, but

* The late Mr. F. J. Foot, who surveyed this district, and myself, were enabled to determine the dip of the beds with the most perfect accuracy, by means of the heights given on the six-inch Ordnance maps. In two or three places we could walk on the topmost bed of limestone with a little cliff of coal-measure shale close to us resting on that bed, for distances of half or three-quarters of a mile down the gentle slope of the dip, from the spot where one altitude was given to that where another appeared on the map—the difference of the altitudes, of course, giving us the fall in the distance traversed. This was always 1 in 41, which is almost exactly $1\frac{1}{2}°$.

† The picturesque atmospheric effects of sunshine and cloud upon these hills of pale grey stone, with their sculptured tops and terraced sides, and their deeply-winding valleys, along which the slightly-inclined lines of stratification recede to the vanishing point, are often most peculiar, and such as I never saw in any other part of the world, while the setting sun converts the pale grey into exquisite tints of violet and rose colour. The detached outlying

one band of chert nodules is to be seen, and not a single inch of shale or any other rock but grey limestone, every bed of which seems to be composed mainly of the minutely broken fragments of the joints of encrinites. The upper part of the limestone thus admirably exposed in this hill country forms probably about half the whole formation, the lower portion spreading to the east over a low country, from beneath which the Old Red Sandstone rises gently out on to the hills called Slieve Boughta.

In some other districts, as for instance in Limerick and the south of Clare, Mr. Kinahan and Mr. Foot could have divided the Carboniferous limestone into three or four subordinate groups by lithological characters, which were constant for many miles; and in the neighbourhood of Dublin Mr. Du Noyer and I have divided it into two—an upper and a lower limestone. None of these subdivisions, however, have any more than a local character, and none of them are supported by palæontological characters depending on time, but only by such as depend on the nature of the place of deposit.

Coal-measures.—Over all the south of Ireland the Carboniferous limestone is succeeded by a series of black shales and grey gritstones or flagstones, containing in their upper portion thin beds of coal. In all probability these beds represent only part of the millstone grit and Yoredale series of England, and are consequently of older date than the true Coal-measures of the British type.

The Irish Coal-measures may be subdivided, as they are in the following section, into three sub-groups. These sub-groups are recognis-

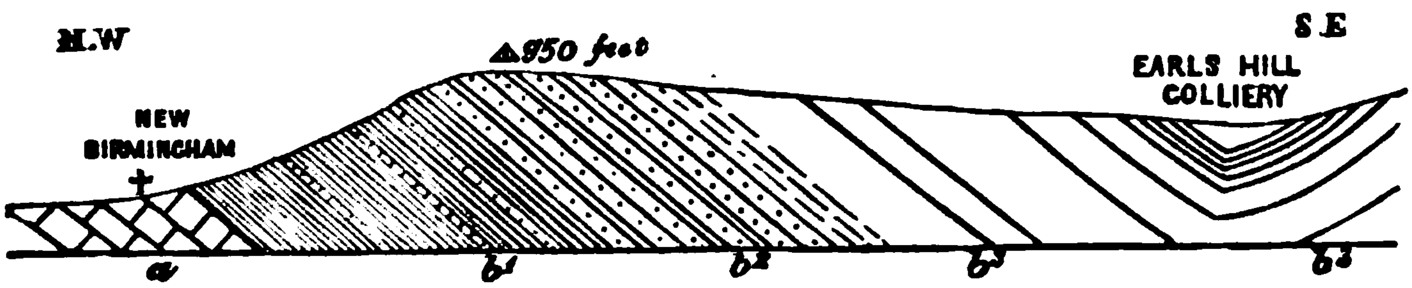


Fig. 159.

Section of the Slievardagh Coalfield, County Tipperary.

Length of section, about 1¼ mile.

		Feet.
b^3	Black shales and grey grits containing nine small beds of coal . .	1300
b^2	Flagstone series (grey sandy flags with black shales)	700
b^1	Black shales, with occasional bands of thin grit	800
a	Carboniferous limestone.	2800

able throughout the counties of Cork, Limerick, and Clare, Tipperary, Queen's County, Carlow, and Dublin, wherever a sufficient thickness of the Coal-measure group comes over the limestone. The lower one,

hills often resemble, at a distance, vast fortresses with long sloping stone glacis, from which numerous curtain-walls rise at intervals, one above another, till they terminate in a small citadel at the top.

b^1, has a very distinct assemblage of fossils, which always occur in it, and sometimes in the greatest profusion, and in the most excellent state of preservation. These fossils are the following :—

Aviculopecten papyraceus . . .	Foss. gr. 17, *b*.
———— variabilis . . .	M'Coy, Carb. foss., t. 16, f. 7.
Lunulacardium Footi . . .	Expl. 142, G. S. I.
Posidonomya Becheri . . .	Phill. Pal. foss., t. 20.
———— membranacea . .	M'Coy, Carb. foss., t. 13.
Goniatites sphæricus . . .	Phill. G. Y., t. 19.
Orthoceras scalare . . .	Sandberger's Nassau, t. 19, f. 5.
———— Steinhaueri . . .	Phill. G. Y., t. 21.

The flagstone series, b^2, is equally characterised by tracts of marine animals (mollusca or annelida), sometimes of the most remarkable character, the whole surface of large slabs being a matted network of long tortuous impressions, indentations on the upper surface, and ridges or casts of indentations on the lower surfaces of the flagstones.*

If we tabulate the groups of the Carboniferous formation as it exists in the south of Ireland, and give each group its maximum thickness, we shall have the following series :—

		Feet.	
3. Coal-measures.	*c*. Shales, etc., with coal	1800	
	b. Flagstone series	500	
	a. Lower shales	800	
		——	3100
2. Carboniferous Limestone.	*b*. Subdivisions varying in different parts	2800	
	a. Lower limestone shale	200	
		——	3000
1. Carboniferous Slate.	*b*. Black slate	2000	
	a. Do., with Coomhola grit	3000	
		——	5000
Yellow sandstone, or Upper Old Red Sandstone, 800 or .			900
			12,000

North of Ireland.—In the north of Ireland, according to the map of Sir R. Griffith, the Carboniferous formation is capable of still further subdivision, and consists of the following groups :—

		Feet.	
2. Coal-measures, etc.	Coal-measures	2000	
	Millstone grit	500	
	Yoredale beds (Co. Fermanagh †) . .	500	
	[Forward] . .	——	3000

* See Mr. Baily's Palæontological Notes, in the Explanation of Sheets 102 and 112, and 141 and 142, of Geological Survey of Ireland.

† In Leitrim, Fermanagh, and Tyrone, there are true representatives of the Yoredale series of England, as well as of the Millstone Grit and Coal-measures. [Mr. Hull.] The Carboniferous Rocks of Ballycastle, Co. Antrim, are considered by Mr. Hull to belong to the type of those of Scotland, and to be the representatives of the Carboniferous Limestone and Calciferous Sandstone series of that country. With other characters of resemblance they contain "black-band" ironstones.—*Journ. Royal Geol. Soc. of Ireland*, 1871.

		Feet.	Feet.
	[Brought forward] . .		3000
1. Carboniferous Limestone.	Upper limestone	500	
	Upper calp shale	500	
	Calp sandstone	300	
	Lower calp shale	500	
	Lower Limestone	800	
	Lower limestone shale	100	
			2700
Yellow sandstone			500
			6200

The principal differences between the north and south are in the development of thick sandstones in the lower part of the Coal-measures in the north, forming a group like the Millstone Grit of Derbyshire, and the separation of the Carboniferous limestone by the development of a set of shales and sandstones called "the Calp" in its central portion, and the entire absence of the Carboniferous slate group. The coals also in the upper part of the Coal-measures are good coals, of the character called bituminous, while those of the south of Ireland are more anthracitic. The Carboniferous series, as thus described, may be seen in the counties of Leitrim, Fermanagh, and Armagh.

The changes which take place in the Carboniferous Limestone by the introduction of shales and sandstones as we proceed from the central parts of Ireland northwards are of a similar character to those to be observed in the case of the same formations in England, and are probably due to similar causes. In each case it will be observed that, with the introduction of truly sedimentary beds, there is a proportionate decrease in the thickness of the limestone beds themselves.

Contemporaneous Volcanic Rocks in the Carboniferous System of Britain.

"The base of the Carboniferous series in Cornwall and South Devon is marked by the occurrence in it of sheets of trappean ash and of crystalline amygdaloidal greenstone, similar to the igneous masses among the neighbouring Devonian rocks. The ash is sometimes coarse and full of fragments of cellular trap, as in the conspicuous hill of Brent Tor. In describing the rocks of that locality, Sir Henry de la Beche pointed out the remarkable resemblance of the Brent Tor to a volcano, and the probability that the ash and greenstone were erupted over the sea-bottom, where they became interstratified with the ordinary marine sediments.*

"In the centre of England the well-known toadstones of Derbyshire indicate intermittent volcanic activity during the formation of the

* De la Beche, *Devon and Cornwall*, p. 122.

Carboniferous Limestone. They consist of three principal beds of trap, sometimes compact and dark, approaching basalt in texture, but usually more earthy and highly amygdaloidal. These beds average each about 60 or 70 feet in thickness, and preserve their course for many miles between the strata of limestone. Mr. Jukes has pointed out that each of them is probably the result of not merely one eruption, but rather consists of different flows proceeding from distinct vents, and uniting into one sheet along a common floor.* This conclusion, he says, 'was confirmed, in 1861, on visiting Buxton with the eminent Swiss geologists, Messrs. Escher and Merian, and their companion M. Stöhr, when the railway cutting a little below Buxton, down the valley of the Wye, laid open the toadstone, with the limestone above and below it. Two solid beds of toadstone were exposed, proceeding from opposite ends of the cutting, towards each other, but not overlapping, with beds of purple and green ash, greatly decomposed into clay, both above and below each bed, and between the two, the whole forming a rather irregular composite accumulation, with a total thickness of about 50 feet.'

"Farther north the counties of Durham and Northumberland are traversed for many miles by interpolated sheets of basalt-rocks, of which the most important is known as the Great Whin Sill. It does not appear that these masses have yet been investigated in such detail as to indicate how far they may be actually contemporaneous with the Carboniferous Limestone series in which they occur.

"Passing into Scotland, we find the Carboniferous formations of the broad midland valley full of the most striking evidences of volcanic activity. From the very bottom of the system up to at least the top of the Carboniferous Limestone series, volcanic rocks of many varieties abound. In the west, great sheets of different porphyrites, with interbedded tuffs, sandstones, and conglomerates, lie in the lower part of the formation, and rising in broad masses, bed above bed, form that conspicuous chain of terraced heights which stretches from near Stirling through the range of the Campsie, Kilpatrick, and Renfrewshire hills, to the banks of the Irvine in Ayrshire, and thence westwards by the Cumbrae Islands and Bute, to the south of Arran. In the eastern districts, instead of such wide-spread sheets of volcanic rock, the Carboniferous series includes hundreds of minor patches of tuff, basalt-rocks, and porphyrite. The area of the Lothians and Fife seems to have been dotted over with innumerable little volcanic vents, breaking out and then disappearing one after another during the lapse of the Carboniferous period up to about the close of the Carboniferous Limestone.† The very limited area occupied by the erupted material is often

* *Manual of Geology*, 2d edit., p. 523.

† See MacLaren's *Fife and the Lothians*; *Mem. Geol. Survey*; "Geology of Neighbourhood of Edinburgh," *Trans. Roy. Soc. Edin.*, vol. xxii. p. 644.

remarkable. A mass of tuff, a hundred feet thick or more, may be found intercalated between certain strata, yet at a distance of a mile or two the same strata may show no trace of any volcanic material. Nowhere is this feature more wonderfully exhibited than in the coal-field of Dalry, in the northern part of Ayrshire. The blackband ironstone of that district appears to have been deposited in hollows between mounds and cones of volcanic tuff, sometimes 600 feet high, round and over which the later members of the Lower Carboniferous formation were deposited. Hence the shafts of the pits are sometimes sunk for 100 fathoms through the tuff, and at that depth mines are driven horizontally through the volcanic rocks to reach the ironstone beyond. In other districts the interstratification of beds of tuff and sheets of basalt and dolerite (melaphyre) amongst highly fossiliferous limestones and shales presents many points of interest. In this respect the range of the Linlithgowshire hills is specially deserving of study.

"The great Carboniferous Limestone series of Ireland contains evidence that here and there, at various intervals during its formation, minor volcanic vents were active on different parts of the sea bottom. In the county of Limerick masses of trap 1200 and 1300 feet thick, with well-marked ashy interlacings, lie among the limestones."*

Characteristic Fossils.

A list has been already given of the characteristic fossils of the lower part of the series in Ireland. Some of the fossils there mentioned, however, are not restricted to that part, but occur throughout the Carboniferous series, and will be mentioned again in the following list. One general characteristic of the formation is the abundance of plants. These occur throughout, and are not, I believe, characteristic of one part of it more than another, except that they are found in shales and sandstones, or the washings of the land, rather than in limestones, the product of the ocean. It does not appear that there is any essential difference in Scotland between the plants found with the coals at the base of the series, and those found near the top, some species being locally peculiar in each case, but occurring in other beds in other places. Similarly, although the marine shells, etc., are found principally in the limestones, as might be expected, yet they are found occasionally in the shales and sandstones in which coals occur, together with other shells that look something like fresh-water shells, but nevertheless may be marine.

* See *Mem. Geol. Survey Ireland;* Explanation to Sheets 143, 144, 153, and 154. The above account of British Carboniferous volcanic rocks is from the Editor's Address to the Geological Section of the British Association, 1867.

The different assemblages of fossils, therefore, found in different parts of the Carboniferous series, may be only locally characteristic of

Fossil Group No. 15.

Carboniferous Plants.

a. Calamites cannæformis. c. Sigillaria reniformis.
b. Alethopteris lonchitica. d. Lepidodendron elegans.
e. Stigmaria ficoides.

those parts, their limitation depending on the nature of the "station" in which, and not upon the time during which, they lived.

Plants . .	Alethopteris lonchitica (Fern) .	Foss. gr. 15, *b*.
	Asterophyllites grandis . .	Lindl. and Hutton, foss. flor., t. 17, t. 19, fig. 2.
	——— foliosus . .	*Ibid.* t. 25, fig. 1.
	Calamites cannæformis . .	Foss. gr. 15, *a*.
	Lepidodendron elegans . .	Foss. gr. 15, *d*.
	Lepidostrobus ornatus . .	Lind. Hutt. foss. flor., t. 26, and t. 163.
	Neuropteris gigantea (Fern) .	*Ibid.* t. 52.
	Sigillaria reniformis . .	Foss. gr. 15, *c*.
	Sphenopteris latifolia (Fern) .	Lind. and Hutt. foss. flor., t. 178.

Plants . . .	Stigmaria (roots and rootlets) .	Foss. gr. 15, *a*.
Actinozoa . .	Amplexus coralloides . .	Foss. gr. 16, *b*.
	Lithostrotion affine . .	Foss. gr. 16, *c*.
	Michelinia favosa . . .	Foss. gr. 16, *a*.
	Syringopora ramulosa . .	Tab. View.
Polyzoa . .	Fenestella antiqua, membranacea, etc.	Phill. G. Y. and Pal. foss.
Echinodermata	Actinocrinus triacontadactylus	Tab. View.
	Archæocidaris Urii . .	M'C. Carb. foss., t. 27.
	Cyathocrinus calcaratus . .	Tab. View.
	Palæchinus sphæricus . .	Foss. gr. 18, *b*.
	Pentremites Derbiensis . .	Foss. gr. 18, *c*.
	Platycrinus lævis . . .	Foss. gr. 18, *a*.
	Poteriocrinus granulosus .	Phill. G. Y. 2, t. 4.
	Rhodocrinus bursa . .	*Ibid.*, t. 4, fig. 24, 25.
Annelida . .	Spirorbis carbonarius . .	Ly. Man., fig. 545.
Crustacea . .	Belinurus Regina . . .	Expl. sh. 137, G.S.I.
	——— rotundatus . .	Ly. Man., fig. 547.

Fossil Group No. 16.

Carboniferous Fossils.

a. Michelinia favosa.
b. Amplexus coralloides.
c. Lithostrotion affine.
d. Terebratula hastata.
e. Spirifera striata.
f. Producta semireticulata.

Crustacea . .	Belinurus trilobitoides . .	*Buckl. B.T.
	Brachymetopus (Phillipsia) Ouralicus.	
	Dithyrocaris Colei . . .	Port. G.R., t. 12.
	Griffithides globiceps . .	*Ibid.*, 311.
	Phillipsia pustulata . .	Foss. gr. 18, *d.*
Brachiopoda .	Athyris planosulcata . .	†M'Coy, Carb. foss, t. 21, fig. 6.
	Discina nitida . . .	Phill. G. Y., t. 11, fig. 10.
	Orthis resupinata . . .	Foss. gr. 17, *a.*
	Producta aculeata, scabricula, etc.	Phill. G. Y.
	——— semireticulata . .	Foss. gr. 16, *f.*
	Rhynchonella acuminata .	Tab. View.
	——— pleurodon .	Foss. gr. 14, *b.*
	Spirifera cuspidata . .	Foss. gr. 14, *a.*

Fossil Group No. 17.

Carboniferous Fossils.

a. Orthis resupinata.
b. Aviculopecten papyraceus.
c. Cardiomorpha oblonga.
d. Pleurorhynchus Hibernicus.
e. Euomphalus pentangulatus.
f. Bellerophon tangentialis.

* Buckland's *Bridgewater Treatise.*

† Phillips's *Geology of Yorkshire and Palæozoic Fossils*; and M'Coy's *Carboniferous Fossils*, published by Sir R. Griffith.

Brachiopoda .	Spirifera glabra . . .	Tab. View.
	——— pinguis . . .	Phill. G. Y.
	——— striata . . .	Foss. gr. 16, *e*.
	Terebratula hastata . .	Foss. gr. 16, *d*.
Conchifera .	Aviculopecten papyraceus .	Foss. gr. 17, *b*.
	Cardiomorpha oblonga . .	Foss. gr. 17, *c*.
	Pleurorhynchus (Conocardium) Hibernicus	Foss. gr. 17, *d*.
	Posidonomya Becheri . .	Tab. V. and Ly. Man., fig. 584.
Gasteropoda .	Euomphalus pentangulatus .	Foss. gr. 17, *e*.
	Loxonema Lefebvrei. . .	De. Koninck. Pl. 41, fig. 7.
	Macrocheilus ovalis . .	M'Coy, Carb. foss.
	——— pusillus.	
	Natica elliptica . . .	Phill. G. Y., t. 14, fig. 23.
	Patella mucronata . . .	Phill. G. Y., fig. 3.
	Pleurotomaria carinata . .	Phill. G. Y., t. 15, fig. 1.

Fossil Group No. 18.

Carboniferous Fossils.

a. Platycrinus lævis.
b. Palæchinus sphæricus.
c. Pentremites Derbiensis.
d. Phillipsia pustulata.
e. Nautilus biangulatus (or carinatus).
f. Goniatites Listeri.
g. Cyrtoceras Gesneri.

Gasteropoda .	Trochella prisca . . .	M'Coy, Carb. foss., t. 7, fig. 1.
Heteropoda .	Bellerophon hiulcus . .	Tab. View.
	——— tangentialis .	Foss. gr. 17, *f*.
	Porcellia Puzio.	
Cephalopoda .	Actinoceras giganteum . .	G. Y. 2, t. 21.
	Cyrtoceras Verneuillianum .	Koninck, t. 44.
	——— Gesneri . . .	Foss. gr. 18, *g*.
	Goniatites Listeri . . .	Foss. gr. 18, *f*.
	——— sphæricus . .	Tab. View.
	Nautilus biangulatus (or carinatus)	Foss. gr. 18, *e*.
	Orthoceras Steinhaueri . .	Phill. G. Y. 2, t. 21.
	Poterioceras fusiforme . .	Tab. View.
Fish	Cladodus striatus . . .	Foss. gr. 19, *a*.
	Cochliodus contortus . .	Foss. gr. 19, *d*.
	Ctenacanthus brevis.	
	Diplodus gibbosus . . .	Foss. gr. 19, *h*.
	Rhizodus Portlockii . .	Foss. gr. 19, *c*.
	——— Hibberti . .	Ly. Man., fig. 556.
	Orodus ramosus . . .	Foss. gr. 19, *g*.
	Pœcilodus Jonesii . . .	Foss. gr. 19, *f*.
	Psammodus porosus . .	Foss. gr. 19, *e*.

Fossil Group No. 19.

Carboniferous Fish Teeth.

a. Cladodus striatus.
b. Petalodus Hastingsiæ.
c. Rhizodus Portlockii.
d. Cochliodus contortus.
e. Psammodus porosus.
f. Pœcilodus Jonesii.
g. Orodus ramosus.
h. Diplodus gibbosus.

Reptilia (*Labyrinthodonta*)	Anthracosaurus Russelli .	Q.J.G.S., vol. xix. p. 56.
	Loxomma Allmanni .	*Ibid.*, vol. xviii.
	Pholidogaster pisciformis.	
	Heraterpeton Galvani .	Trans. R. I. Ac., vol. xxiv.
	Urocordylus Wandesfordii .	*Ibid.*
	Lepterpeton Dobbsii .	*Ibid.*
	Ophiderpeton Brownriggii .	*Ibid.*
	Dolichosoma Emmersoni .	*Ibid.*
	Ichthyerpeton Bradleyæ .	*Ibid.*
	Erpetocephalus rugosus * .	*Ibid.*

Foreign Localities.

On the continent of Europe the development of the rocks of this period is generally inferior to that observable in the British Islands. Having learnt the succession of the beds, and their organic remains, however, in our own country, we are enabled to trace a corresponding order in other parts.

Belgium.—According to Mr. Dumont—

SYSTÈME HOUILLIER.	4. Alternations of "ampelite" (sandstone), shale, and coal.
SYSTÈME CONDRUSIEN.	3. Crinoidal limestone, dolomite, *producta*-limestone, with chert and anthracite. 2. Grey sandstone, soft sandstone, and anthracite. 1. Grey shales, calcareous shales, dark limestone, and pisolitic iron ore (oligiste).

The plants of No. 4 correspond to those of our Coal-measures. The large *Productæ* and other fossils of No. 3 correspond in the main with those of the Carboniferous or Mountain Limestone of the British Islands. The lowest division, No. 1, contains *Spiriferæ*, *Cyathophyllum mitratum*, *Pleurotomariæ*, and other fossils found also in the lower divisions of Northumberland and Scotland.

The coalfield of Liege has long been celebrated. The rocks in that neighbourhood, and about Namur, seemed to me greatly to resemble those of the south of Ireland, the Coal-measures being apparently affected by slaty cleavage, thick Carboniferous Limestone appearing below them, with still lower beds resembling the Carboniferous slate.

France has Coal-measures in the coalfields of Valenciennes in the north, which is the western continuation of that of Belgium, and is covered towards the west unconformably by the Chalk; and also in the southern coalfields of St. Etienne, and some other smaller districts. Much of the lower part of the formation, however, consists of clay slate, and altered rocks, which were at one time taken for much older formations. Sir Roderick Murchison showed that the slate rocks of Le Fôret, near Vichy, pierced by syenites and porphyries, were in reality Carboniferous rocks.†

Carboniferous rocks occur in Rhenish Prussia, having an area of about 900 square miles; Westphalia, north-east of Dusseldorf; Bohemia and Silesia, which are separated from each other by the Silurian and Devonian rocks of the Riesen Gebirge; in Russia, Spain, and Portugal.‡

* The above seven genera of Labyrinthodont Amphibia, from Jarrow Colliery, County Kilkenny, were described by Professor Huxley in 1866, and are figured in the *Transactions of the Royal Irish Academy*, vol. xxiv. Three other genera are mentioned as occurring at the same colliery.

† *Quart. Journ. Geol. Soc.*, vol. vii. p. 13.

‡ Short descriptions of these coalfields are given in Hull's *Coalfields of Great Britain*.

North America.—According to Dr. Dawson the Nova Scotian Carboniferous system may be divided as follows :—

UPPER GROUP.	3. Greyish and reddish sandstone and shales, with beds of conglomerate, and a few thin beds of limestone and coal. 3000 feet and more.
MIDDLE OR GOOD COAL GROUP.	2. Grey and dark-coloured sandstones and shales, with red and brown beds, coal, ironstone, and bituminous limestone. 4000 feet and more.
LOWER OR GYPSIFEROUS GROUP.	1. Red and grey sandstones and conglomerates, and red and green marls and shales, with thick beds of gypsum and limestone. 6000 feet and more.

The fossils of No. 1 consist of *Productæ*, *Terebratulæ*, Encrinites, and Corals, etc., in the limestones, many analagous to, and some even identical with, those of the Carboniferous limestone of Britain. Scales of *Holoptychius* and *Palæoniscus* have also been discovered. *Lepidodendron* and other plants occur in the sandstones. In No. 2, *Stigmaria*, *Sigillaria*, and other genera of plants occur in abundance, generically identical with those of our Coal-measures; *Cypris*, *Modiola*, a land-shell (*Pupa*), the oldest air-breathing mollusc yet known; Ganoid fish, and three species of Reptiles also are known, apparently of terrestrial species. In No. 3, Calamites, Ferns, and Coniferous wood are found.

Altogether there is a thickness of more than 14,000 feet, without reaching any exact base, or arriving apparently at the very highest beds of the series. There are seventy-six beds of coal, of which, however, most are only one or two inches thick, although one seam sunk through by Mr. Henry Poole at the Albion Mines, Pictou, was found to be about forty feet thick.* Some of the beds of group 1, consisting of sandstones with variegated marls and gypsum, and a few beds of coal, were seen formerly by myself in Newfoundland, on the south shore of St. George's Bay, and at the northern extremity of the Grand Pond.†

United States.—Professor Rogers has grouped the Carboniferous rocks of the United States as under :—

3. UPPER CARBONIFEROUS OR COAL-MEASURE GROUP.	Coal-measures, alternations of Sandstones, shales, and coals, like groups 2 and 3 of the Nova Scotia district, but thinning out westward, so as to be only 3000 feet in Pennsylvania, 1500 in the Illinois Basin, and not more than 1000 in Iowa and Missouri.
2. MIDDLE CARBONIFEROUS GROUP.	In Pennsylvania, soft red shales, and argillaceous red sandstones, 3000 feet. In Virginia— *c.* Blue, olive, and red calcareous shales, with thick red and brown sandstone. *b.* Light blue limestone, sometimes oolitic. *a.* Buff, greenish, and red shales, with sandstone. Total thickness, 3000. In the Western States— *b.* Grey and yellow sandstone. *a.* Light blue and yellow limestone,‡ 1000 feet.
1. LOWER CARBONIFEROUS GROUP.	White, grey, and yellow sandstones, alternating with coarse siliceous conglomerates, and dark blue and olive-coloured slates. In some places contains black carbonaceous slate, and a bed or two of coal. 2000 feet thick in Pennsylvania, thinning out to nothing in the north-west.

* Dawson's *Acadian Geology*. † Jukes' *Report on Geology of Newfoundland*.

‡ The light blue limestone mentioned above thickens towards the south-west, and dies away to the north-east in Pennsylvania.

The fossils in group No. 1 are said to be coal plants in some parts, and marine remains, crinoids, and molluscs, in others. Those of No. 2 are like those of No. 1 of the Nova Scotia district, generically identical with the fossils of the Carboniferous limestone of Britain. Those of No. 3 are in like manner coal plants, belonging to the same generic forms as the British, but with many local and peculiar species. The marine beds contain corals, shells, and fishes, and the littoral beds show the tracks of reptiles of the order Labyrinthodontidæ.

India.—Several large and important coalfields exist in India, as those of Damoodah, Talcheer, Nagpur, and others. There is, however, much doubt whether these are really of the Carboniferous period, since they contain fossil plants of the genera *Pecopteris*, *Glossopteris*, *Vertebraria*, *Phyllotheca*, etc., which are believed to be rather of Triassic or Oolitic age than of the Carboniferous.*

Australia.—There are large formations in Australia which are certainly of Upper Palæozoic age, consisting of sandstones, shales, and limestones, containing shells of the genera *Producta*, *Spirifera*, *Leptæna*, *Orthonota*, *Pecten*, *Pterinea*, *Pachydomus*, *Platyschisma*, *Bellerophon*, *Conularia*, stems of crinoids, a small trilobite, etc. etc. Associated with these rocks, and apparently forming the upper part of them, are other shales and sandstones of precisely similar character, containing good beds of coal, and having fossil plants of the genera *Glossopteris*, *Tæniopteris*, *Pecopteris*, *Phyllotheca*, *Vertebraria*, etc., precisely like those of India. These coal-bearing beds are accordingly believed by some persons to be of much later date than the beds below them, which contain palæozoic genera of animal remains. I certainly could see no reason myself, in Tasmania and New South Wales, for introducing any separation among these beds, which seemed to be all part and parcel of the same great formation of pale sandstones, separated by shales, and containing calcareous beds in the lower part, and coal beds in the middle part of the formation. In New South Wales the beds are all nearly horizontal, and the section quite clear, as described by myself in a paper, of which the following is an abstract.†

5. Dark brown shales, with impressions of plants . . .	300 feet and more.
4. Sydney sandstone, thick white or light-yellow sandstone, with quartz pebbles occasionally, and partings of shale . .	700 feet.
3. Alternations of shales and sandstones	400 feet.
2. Shales containing two or three good beds of workable coal, 6 feet thick	200 to 300 feet.
1. Wollongong sandstones, thick dark-grey, reddish-brown often calcareous, with large calcareous concretions . . .	400 and more.

This is only a part of the series, as there may be beds below No. 1, and others above No. 5.

The characteristic fossils of No. 1 are—*Stenopora crinita*, *Producta rugata*, *Spirifera subradiata*, *S. Stokesii*, *Avicula*, *Pachydomus*, *Orthonota*, *Pleurotomaria*, *Bellerophon*, etc. Those of No. 2 are—*Glossopteris Browniana*, *Vertebraria Indica*, *Pecopteris australis*, *Phyllotheca australis*. There are fish said to have been found by the Rev. W. B. Clarke in No. 3 or 5, together with fragments of plants. No fossils have yet been found in No. 4. The same observer has written largely on the structure of this country.‡ He proposes the names of Hawkes-

* See papers by Dr. T. Oldham, *Mem. Geol. Survey India*, vol. i.; and by Sir C. Bunbury in *Quart. Journ. Geol. Soc.*, vol. xvii.; Hislop on Indian Plant-beds, *op. cit.* vol. xi.

† See *Quart. Journ. Geol. Soc.*, vol. iii.; also *Sketch of Phys. Structure of Australia*—Boone.

‡ *Quart. Journ. Geol. Soc.*, vols. iv. viii. xvii. xviii. xxii., and in separate publications.

bury Sandstone for the group No. 4 of the above section, and Waianamatta Shales for group No. 5. The city of Sydney stands on beds about the junction of 4 and 5, so that the coal beds of Hunter's River and Illawarra lie underneath it at a depth of about 1200 feet. Mr. Clarke's Waianamatta shales form the surface-rock of the great part of the county of Cumberland, the Sydney or Hawkesbury sandstones cropping out all round it, both along the coast and in the Blue Mountain range in the interior, and the coals are everywhere found a little below the base of this sandstone, both on the south at Illawarra, on the north at Hunter's River, and in the gullies of the Blue Mountains, according to Count Strzelecki.

CHAPTER XXXIV.

PERMIAN PERIOD.

In the examination of the great series of British rocks, a large group of reddish-coloured sandstones and marls is met with, lying above the Carboniferous rocks, similar in general aspect to those which lie below them. These red sandstone groups were called the Old and New Red Sandstone. Under the term "New Red Sandstone" were included all the red strata lying between the Coal-measures and the Lias. The necessity for separating these strata into two distinct parts was recognised by Sir R. I. Murchison. This separation has indeed been made so wide as to class the two parts in different epochs, the one forming the uppermost of the Palæozoic, while the other forms the base of the Mesozoic series.

North-West of England.—The Permian beds of Lancashire consist of three members—1. The Lower Red Sandstone; 2. Red Marls, with fossiliferous and thin magnesian limestones; 3. Upper, or St. Bees Sandstone. The first has been estimated by Professor Harkness to attain at Penrith a thickness of about 3000 feet; and, as shown by Mr. Binney, is well developed at Manchester, and along the southern margin of the Lancashire coalfield. The second beds were first referred by Mr. Binney to the Permian series, as they contain fossils of the genera *Schizodus*, *Bakevellia*, *Tragos*, etc.* The third member, so finely developed along the cliffs of St. Bees' Head, has been referred by Sir R. Murchison to this formation, though formerly considered to be of Triassic age.

Durham and the North-East of England.—Professor Sedgwick described the rocks of Durham as follows:—†

	Feet.
6. Red gypseous marls	100
5. Thin bedded grey limestone	80
4. Red gypseous marls, slightly saliferous . . .	200
3. Magnesian limestone	500
2. Marl slate	60
1. Lower red sandstone	200

* *Mem. Lit. and Phil. Soc. Manchester*, vol. xii.

† *Trans. Geol. Soc.* vol. iii. See also the vol. of the Palæontographical Society on Permian Fossils, by Professor W. King, 1848; and an excellent paper on the Permian rocks of South Yorkshire, by Mr. Kirkby, *Quart. Journ. Geol. Soc.*, vol. xvii.

Of these, No. 1 is the same as the Rothe-todte-liegende of Germany; No. 2 is identical with the Kupfer Schiefer, containing many of the

Fossil Group No. 20.
Permian Fish.
a. Platysomus striatus. b. Cœlacanthus granulosus. c. Palæoniscus comptus.

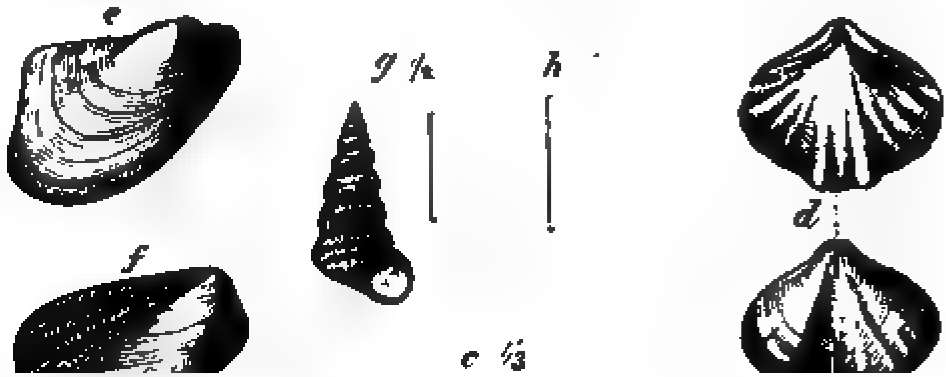
same peculiar species of fish; and the beds above may be equally paralleled with the Zechstein and Bunter Schiefer.

1. The **Lower Red Sandstone** is a very irregular deposit, lying unconformably on the Coal-measures, and in hollows eroded in their surface. Nevertheless it contains plants of the same species as those of the Coal-measures.

2. The **Marl Slate** is a brown indurated fissile shale, with occasional beds of thin compact limestone.

Characteristic Fossils.—Plants: Neuropteris Huttoniana; Caulerpites selaginoides.
Brachiopoda: Lingula mytiloides; Discina nitida; Productæ and Spiriferæ.
Fish: Palæoniscus elegans, P. comptus (Foss. gr. 20 *c*), P. glaphyrus, etc.; Platysomus macrurus; Acrolepis Sedgwickii; Pygopterus mandibularis, etc.; Cœlacanthus granulosus (Foss. gr. 20, *b*).

3. The **Magnesian Limestone** is a singularly diversified mass of limestones, sometimes compact, at others crystalline, brecciated, earthy, globular, oolitic, cellular, etc.; some beds like piles of cannon or mus-



Fossil Group No. 21.
Permian Fossils.

a. Synocladia virgulacea.
b. Fenestella retiformis.
c. Producta horrida.
d. Camarophoria crumena.
e. Bakevellia antiqua.
f. Pleurophorus costatus.
g. Loxonema fasciatum.
h. Macrocheilus symmetricus.

ket balls, others like bunches of grapes, etc.; some very hard, some quite friable, some thin and flexible. General colour shades of yellow, sometimes red and brown.

Its characteristic fossils are numerous, the following being a selected list :—

Plants	Voltzia Phillipsii . . .	Lind. Foss. flo. 195.
Actinozoa . . .	Polycœlia profunda . . .	Pal. Soc. King. and Ed.
Polyzoa . . .	Fenestella plebeia (retiformis) .	Foss. gr. 21, *b*.
	Synocladia virgulacea . .	Foss. gr. 21, *a*.
	Thamniscus dubius . . .	King, Per. foss.
Brachiopoda . .	Camarophoria crumena (Schlotheimi)	Foss. gr. 21, *d*.
	Producta horrida . . .	Foss. gr. 21, *c*.
	Spiriferina cristata . . .	*King, Per. foss.

* King's *Permian Fossils*, Pal. Soc.

Brachiopoda . .	Strophalosia Goldfussii . .	King, Per. foss.
Conchifera . .	Monotis (Avicula) speluncaria .	*Ibid.*
	Axinus obscurus . . .	*Ibid.*
	——— truncatus . . .	*Ibid.*
	Bakevellia antiqua . . .	Foss. gr. 21, *e.*
	Cardiomorpha modioliformis .	King, Per. foss.
	Pleurophorus costatus . .	Foss. gr. 21, *f.*
	Schizodus Schlotheimi . .	King, Per. foss.
Gasteropoda . .	Euomphalus Permianus . .	*Ibid.*
	Loxonema fasciatum . . .	Foss. gr. 21, *g.*
	Macrocheilus symmetricus . .	Foss. gr. 21, *h.*
	Natica Leibnitziana . . .	King, Per. foss.
	Pleurotomaria antrina . .	*Ibid.*
Cephalopoda . .	Nautilus Bowerbankianus . .	*Ibid.*
	——— Frieslebeni . . .	*Ibid.*
Fish	Platysomus striatus . . .	Foss. gr. 20, *a.*

Midland Counties of England.—The magnesian and other limestones of the Durham section die away towards the south, and finally disappear near Nottingham. There is, however, in Warwickshire, Staffordshire, and Shropshire, a great series of beds, occupying the same relative position between the Coal-measures and the Trias, or New Red Sandstone proper, as may be seen from the section in Fig. 160, which

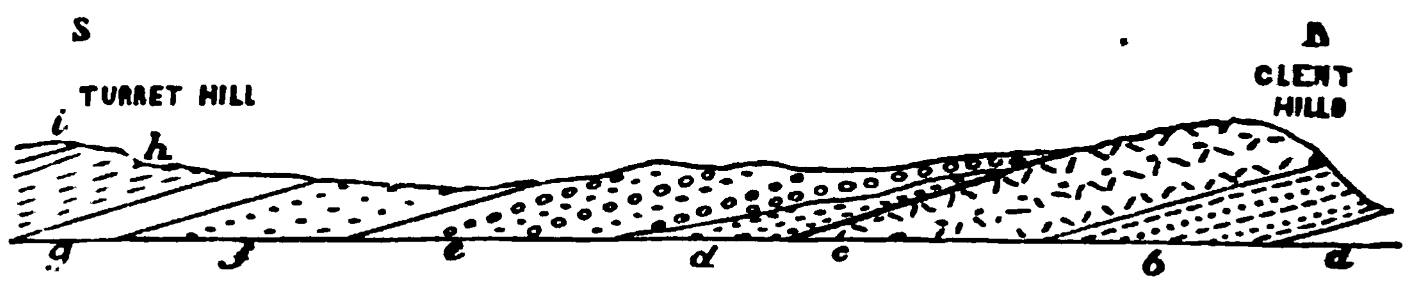


Fig. 160.

Diagrammatic section across the Clent Hills, 900 feet high, from the south end of the South Staffordshire coalfield to the Lias of Worcestershire.

			Feet.
Oolitic.—		*i.* Lias—	
New Red Sandstone.	Keuper.	*h.* Red marls, with salt and gypsum	500
		g. Lower Keuper sandstone; white freestone with thin brown sandstone and marl, and a base of breccia or conglomerate, sometimes calcareous	200
	Bunter.	*f.* Soft bright red and mottled sandstone	500
		e. Pebble beds; uncompacted conglomerate of pebbles of quartz rock, varying from 150 to	300
		d. Soft brick red sandstone, varying from 0 to	550
Permian . .		*c.* Trappoid breccia	450
		b. Red marls and sandstones, with thick cornstone bands . .	400
Carboniferous.		*a.* Coal-measures.	

exhibits the whole series of beds which in that country intervene between the top of the Coal-measures and the base of the Lias. The diagram is constructed partly from Sheet 23 of the Horizontal Sections of the Geological Survey. The parts belonging to the Permian group are those called *b* and *c*.

The marls in group *b* are often remarkable for their deep blood-red

character, and some of the sandstones are likewise dark red. The cornstones are quite like those of the Old Red Sandstone, and were at one time believed to belong to it; one of the earliest descriptions of the cornstone of the Old Red Sandstone being taken in fact from these beds. The trappean breccia *c* consists in some parts so entirely of loose angular fragments of a porphyritic trap that it was believed to be merely the superficial debris derived from the solid trap rock beneath. In other parts, however, it contains square slabs and angular fragments of Llandovery sandstone, and other fragments, so that Professor Ramsay believes that some of them must have been transported by ice.*

A more complete section of the Permian series is exhibited in the Enville district, Shropshire, where the series attains a thickness of 1500 feet, consisting of

1. Upper red and purple sandstones and marls.
2. { *a.* Unconsolidated breccia and marls.
   { *b.* Calcareous conglomerates, sandstones and marls.
3. Lower red and purple sandstones.

The whole of these beds are repeated by a large fault, and thus appear to be twice their actual thickness.

The Permian strata of Central England and Shropshire belong in all probability to the "rothe-todte-liegende," or lower division of the formation. They are described in detail in several memoirs of the Geological Survey, and more recently in one by Mr. E. Hull.†

Ireland.—The red sandstones of Rhone Hill, near Dungannon, Tyrone, containing abundance of *Palæoniscus catopterus*, are probably Permian. Yellow magnesian limestones, exactly like those of Durham, and with many of the characteristic fossils previously mentioned, occur in patches at Ardtrea,‡ County Tyrone, and blocks of it have been found on the shore at Cultra, near Holywood, Belfast.

Scotland.—Several detached areas of red sandstones referred to the Permian series occur in Scotland. Of these the largest are found in Dumfriesshire, lying unconformably upon Lower Silurian and Carboniferous rocks. Their lower beds are sometimes breccias of the underlying rocks, and in some of the sandstones abundant reptilian footprints have been found. In Ayrshire an area of similar red sandstones spreads over the Coal-measures, and exhibits at its base some thick beds of porphyrite and melaphyre, with trap-tuff. Similar volcanic rocks occur at the base of the Permian sandstones of the Nith Valley, above Thornhill. Connected with these remains of Permian igneous action

* *Quart. Journ. Geol. Soc.* vol. xi. p. 185; and *Mems. Geol. Surv., South Staffordshire Coal-field*, 2d edit.

† *On the Permian and Triassic Rocks of the Central Counties*, 1869.

‡ See Professor King's paper (*Dublin Nat. Hist. Review*, No. x.), or *Journal of the Geological Society, Dublin*, vol. vii.

are numerous "necks" of trappean agglomerate, which, ascending vertically through the older rocks, mark the position of volcanic vents.*

VOLCANIC ROCKS OF PERMIAN PERIOD IN BRITAIN.

The volcanic rocks associated with the red sandstones of Ayrshire and Nithsdale, just referred to, are the only examples yet known of in the Permian system of Britain. They consist of dark porphyrites and melaphyres, often very slaggy and amygdaloidal, disposed in gently inclined beds and interstratified with and covered by red gravelly trap-tuffs and ashy sandstones. The tuff is so intimately associated with the sandstone that their contemporaneous origin is evident, while the amygdaloidal rocks have the characters of true lava-flows. Round the outside of the Permian volcanic outlier of Ayrshire, the Carboniferous rocks are pierced with numerous "necks," and similar traces of volcanic orifices are found at intervals across the country even into Fife. It is possible that the later unconformable volcanic rocks of Arthur's Seat, at Edinburgh, may belong to this Permian series.†

In Germany the Permian system abounds in large associated masses of melaphyre, and trappean breccias and conglomerates.‡

Foreign Localities.

When Sir R. I. Murchison and his colleagues examined Russia and the Ural Mountains, they found a great series of "grits, sandstones, marls, conglomerates, and limestone, sometimes enclosing great masses of gypsum and rock-salt," overlying the Carboniferous rocks, but beneath the Trias, and occupying the district which formed the ancient kingdom of Perm. He proposed, therefore, the name of the Permian rocks for them.

The lower part of this deposit agreed with the red beds which in Germany had received the name of the "rothe-todte-liegende," or red dead-layers. These were called "dead" because the copper which was worked in the beds above them died out as the miners came into these beds below. These lower red beds swell out in the Thuringerwald to a thickness of 4000 feet,§ though this must be taken as a mere local exception to their general dimensions.

Above them are certain beds of dark shale, with copper ore, hence called Kupfer-Schiefer, and over that a limestone called the Zechstein, which passes up into a red and mottled marl, called the Bunter-Schiefer.

The section there is—

4. Bunter-Schiefer.
3. Zechstein.
2. Kupfer-Schiefer and Mergel.
1. Rothe-todte-liegende.

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* See Geikie, *Geol. Mag.* vol. iii. p. 245.

† *Ibid.* p. 243. Explanation to Sheet 14 of the Geological Survey of Scotland, p. 22.

‡ See Naumann's *Lehrbuch*; Senft's *Classification der Felsarten*, tab. i. etc.

§ *Siluria*, p. 333.

CHAPTER XXXV.

II. SECONDARY OR MESOZOIC PERIODS.

TRIASSIC OR NEW RED SANDSTONE PERIOD.

THE term Trias is a continental one, as in Germany and the borders of France the rocks deposited during this period formed three well-marked groups. The contemporaneous rocks in Britain were called New Red Sandstone, under which term, however, were included at one time those which have just been described as Permian.

In our own country it is certain that the series is deficient in the central division or Muschelkalk of Germany. The beds we have, however, are divisible into the following groups.*

		Average Thickness.
Keuper.	6. Red marls, with rock salt and gypsum . .	1000 feet.
	5. Lower Keuper sandstone, with thin sandstones and marls (Waterstones)	250 ,,
	4. Dolomitic conglomerate.	
Bunter.	3. Upper red and mottled sandstone . . .	300 ,,
	2. Pebble beds or uncompacted conglomerates .	300 ,,
	1. Lower red and mottled sandstone . . .	250 ,,

The thicknesses given above may be considered an average for the midland counties, but in Cheshire and South Lancashire the formation attains much larger proportions, as ascertained by the officers of the Geological Survey; and from this district the beds thin away towards the south-east, so that in the neighbourhood of Warwick the whole of the Bunter Sandstone has disappeared, and the Keuper beds, themselves much reduced, rest directly on the Carboniferous or Permian formations. The subdivisions are remarkably uniform in character, except in the case of the pebble-beds, which in the north-west form a light red pebbly building stone, but in the central counties become generally an unconsolidated conglomerate of quartzose pebbles.

The Keuper series is introduced by a breccia or conglomerate often calcareous, passing up into brown, yellow, or white freestone, and then into thinly laminated sandstones and marls, with reptilian footprints, etc. (Waterstones). These are ultimately surmounted by the Red Marl series. These red clays or marls contain frequently beds of gypsum, and sometimes beds of rock-salt, which are often as much as 80 or 100

* Hull, *Brit. Assoc. Rep.* 1854, p. 86.

feet in thickness. These are worked largely in the centre of Cheshire, and have also been pierced at the opposite side of the island, at the mouth of the Tees; and in Ireland at Duncrae, near Carrickfergus, County Antrim. The brine springs of Droitwich in Worcestershire, of Shirleywych in Staffordshire, and other places, are derived from such beds. Near Northwich, in Cheshire, the following section shows a part of the thickness of these beds.

	Feet.
Upper strata (marl, etc.)	127
1st bed of rock-salt	85
Indurated marl (locally called Stone)	30
2d bed of rock-salt	106
Indurated marls, with thin beds of rock-salt	151
	499

Over this thickness of 500 feet are other beds of marl, etc., before we reach the base of the Lias, and under it are other marls, so that the entire depth of this group must be considerable.* Section, Fig. 160, p. 608, deduced from the maps and sections of the Geological Survey, shows these beds as they occur in North Worcestershire, to the southward of the South Staffordshire coalfield. They rest here upon the Permian trappean conglomerates *c*, and after dipping gently to the south for some miles, are finally covered by the base of the Lias *i*. In this section the pebble-beds of the Bunter, *e*, rest directly on the Permian *c*, but a subdivision, *d*, is introduced beneath them, to represent the Lower red and mottled sandstone; as in North Staffordshire, it occurs with a thickness of 500 feet.†

Ireland.—The section in the north of Ireland is as follows:—‡

	Feet
Red marls, with gypsum	500
Red salt	22
Marl and salt	26
Pure rock-salt	84
Mixed rock-salt	14
Pure rock-salt	39
Blue bands and freestone, etc.	25
	710

These have other beds of red marl above them, about 100 or 150

* See Ormerod (*Quart. Journ. Geol. Soc.* vol. iv.), who gives the following section from Cheshire:—

Red saliferous and gypseous marls	700 feet.
Waterstones	400 „
Bunter	600 „
	1700

† *Horizont. Sect. of Geol. Survey*, No. 54.

‡ See paper by Mr. J. B. Doyle, *Journ. Geol. Soc. Dub.*, vol. v.

feet thick, over which is the base of the Lias. Underneath these red marl beds of the valley of the Lagan occur red sandstones belonging to the Bunter series, which have been sunk into, near Lisburn, in search of water, for a depth of over 500 feet, without reaching their base.

Scotland.—No definitely marked representatives of the Trias have yet been ascertained in Scotland. Some portions of the yellow sandstones of Elgin, formerly classed as Old Red Sandstone, and in which reptilian remains (*Telerpeton*, *Stagonolepis*, and *Hyperodapedon*) occur, have more recently been referred to the Trias, not from any stratigraphical evidence, but solely on account of the high grade of these organic remains, and because *Hyperodapedon* has been found in the Trias of England. It seems, however, exceedingly doubtful whether this reference is justifiable.*

Avicula Contorta Zone, or Rhætic or Penarth Beds.—Dr. Wright of Cheltenham has described as the uppermost part of the Keuper some beds in the south of England that had hitherto been classed with the Lias.† They are perhaps properly intermediate between the two, and are certainly contemporaneous with the "Kössener schichten" of Suess (or Upper St. Cassian of Escher and Merian). They may be well seen at Garden Cliff, near Westbury-on-Severn, and at Aust and Penarth on the coast of Glamorganshire, where, above the red and variegated marls of the ordinary Red Marl series, there is a conspicuous set of black and dark grey shales about 35 feet thick, containing the Bone-bed, and capped by the grey Rhætic and the Lias Limestones, with *Ammonites planorbis.* In Staffordshire, north of Abbotts Bromley, they were visited by myself in the year 1849, and afterwards mapped by my colleague Mr. H. H. Howell.

These beds have been traced across England, at the outcrop of the Keuper Marls, through the counties of Dorset, Somerset, Gloucester, Worcester, and Warwick, to Lincolnshire. The general section of these beds may be briefly described as consisting (in descending order), from the base of the Lias proper, as follows:—

"White Lias" (of William Smith), composed of a series of white or cream-coloured, more or less argillaceous limestones, and often exhibiting at the top one or two hard and compact smooth-grained beds, resembling lithographic stone in texture and colour, to which the name "Sun Bed" was given by William Smith. This bed is very persistent in Somersetshire. At or near the base of the White Lias, where that series is developed, comes the well-known "Landscape Marble" of Cotham, near Bristol. In Gloucestershire (north of Bristol), where the "White Lias" has almost thinned out, the Cotham Marble was taken as the upper limit of the Rhætic series by Mr. Bristow in his survey of the district. Bivalves are the most abundant fossils met with in the

* See *ante*, p. 568.

† *Quart. Journ. Geol. Soc.* xvi.

White Lias. *Ostræa Liassica* occurs in great numbers at the junction of the Rhætic beds and the Lower Lias; and is also met with, occasionally, in the uppermost part of the White Lias. The White Lias is frequently used as road metal, in the construction of walls, and for ornamental building purposes. Ammonites and Belemnites are altogether absent from the Rhætic series, but appear in great numbers in the overlying Lias.

Beneath the White Lias come the black paper-shales with *Avicula contorta* and *Cardium Rhæticum*. Herein is the Bone-bed, or in some cases Bone-beds, when two or three thin occasional layers of a tough greenish siliceous limestone occur, with iron pyrites, and numerous scales, teeth, bones, and coprolites of Fish and Saurians, so well known to the collectors at Aust Cliff. Besides the Bone-beds, the black paper-shales contain several thin and occasional layers of hard, blue, fissile Limestone, with abundant *Pecten Valoniensis*, *Cardium Rhæticum*, and other fossils.

The third, or lowest of the three stages into which the Rhætic series may be divided, consists of a greater or less thickness of alternations of hard and soft grey or greenish marls, generally without fossils, and passing almost imperceptibly into the variegated red marls of the Keuper, to which, in common with the middle division containing the Bone-bed, they seem to be more nearly allied than to the Lias; while, on the other hand, the "White Lias" appears to be more closely related to the Liassic series.

In several localities an eroded surface has been noticed in the uppermost bed of the White Lias, and traces of the borings of marine shells have also been detected, which would show a "break" or lapse of time between the latest deposition of the Rhætic and the first earliest traces of the Lias in this country. Moreover, the sudden appearance of Ammonites and Belemnites in the Lower Lias is another point which tends to distinguish these beds, and possibly implies the occurrence of a considerable time to allow for such a change of conditions as would be suitable for the incursion of these Cephalopods into the Liassic seas.

At the westernmost extension of the Rhætic beds (between Bridgend and Pyle in Glamorganshire) a marked lithological change in the lower beds has taken place:—Sands and sandstones with *Pullastra arenicola*, etc., replacing the equivalent beds in other localities, denoting that they were deposited in shallower water, nearer the margin of the then existing coast. These sandy beds, with *Pullastra arenicola*, have lately been traced by Mr. H. B. Woodward, in one or two places, on the Mendip Hills of Somersetshire, where also the Lias itself has undergone a very curious siliceous modification.

The Rhætic series varies much in different localities, both in general thickness and in detail. The name of "Penarth Beds" has been given

to this series in England by Mr. H. W. Bristow, at the suggestion of Sir Roderick I. Murchison. This name was considered appropriate to denote the British equivalents of the continental Rhætic series, from the well-developed and striking sections of the beds which may be seen in the cliffs forming the bold headlands of Penarth Roads on the coast of Glamorganshire. Their maximum thickness cannot anywhere exceed 100 feet.*

The Rhætic beds are also represented in the north of Ireland at Lisnagrib and Derrymore, by dark shales and grits, with some of the characteristic fossils of the group;† also at Colin Glen near Belfast, Woodburn near Carrickfergus, and Whitehead near Larne.

Fossil Group No. 22.—Triassic Fossils.

a. Footprints of Labyrinthodon giganteum.
b. Head of Labyrinthodon giganteum.
c. Tooth of Labyrinthodon giganteum.
d. Dipteronotus cyphus.

Characteristic Fossils.—Very few fossils have been found in any part of the New Red Sandstone of the British islands. Tracks, how-

* See Bristow in *Report of the Meeting of the British Association at Bath*, 1864; also in *Geological Magazine*, vol. i. p. 236.

† General Portlock's *Report on Londonderry*, etc., p. 105.

ever, of several kinds of reptile have been found—among others, those of the one formerly called *Cheirotherium*, from the likeness of its foot to the human hand, but since named *Labyrinthodon*, from the structure of its tooth. These impressions have been met with also, I believe, in Permian sandstones. Fig. *a* in the Fossil Group 22 is a reduced representation of these foot-tracks, *b* and *c* being the skull and tooth of the animal supposed to have caused them. Other tracks were exhibited from some of the sandstones of Staffordshire, by the Rev. W. Lister of Bushbury, at the meeting of the British Association at Oxford in 1860. Fragments of fossil wood are often found in the sandstones, interstratified with the red marls of the Keuper, and the fossil fish figured in Foss. Gr. 22, *d*, was procured from the same beds, and described by Sir P. Egerton.* *Hybodus Keuperinus* also may be mentioned as found in these beds, and the teeth of the mammalian *Microlestes* found near Frome, by Mr. C. Moore, in a fissure in Carboniferous Limestone, the contents of which are supposed to be of Rhætic age.

The following fossils are characteristic of the Rhætic or Penarth series:—†

Conchifera	Avicula contorta . . .	Port. G. R., t. 25, A.
	Cardium Rhæticum . . .	? Phill. G. Y., t. 11, fig. 7.
	Modiola minima . . .	Sow. M. C., 210.
	Monotis (Avicula) decussata .	Goldfuss.
	Ostræa Liassica.	
	——— intusstriata.	
	Pecten Valoniensis . . .	Port. G. R., t. 25, A.
	Pullastra arenicola.	
Crustacea .	Estheria minuta, var. Brodieana.	Geol. Tr., vol. v. t. 28.
Fish . .	Acrodus acutus and A. minimus	Agassiz.
	Ceratodus altus, and five others	
	Hybodus minor, and four others	
	Nemacanthus monilifer . .	
	Saurichthys apicalis . . .	

Lie and Position of the New Red Sandstone of the British Islands.—The red rocks just described rest quite unconformably and indiscriminately upon all or any of the groups of rocks mentioned in the previous chapters. The Palæozoic rocks of the British Islands had been tilted, contorted, and fractured, in various directions, and had suffered repeatedly and enormously from denudation, before the deposition of the New Red Sandstone. The broken and varied surface which the Palæozoic rocks generally possess had been produced on them, either completely or very approximately, before this time. The New Red Sandstone reposes upon this surface usually in a horizontal or slightly inclined position, thickly where that old surface is deeply buried, more thinly as it rises towards the present surface of the ground. Where

* *Quart. Journ. Geol. Soc.*, vol. x.

† See also Mr. C. Moore's paper on these beds, *Quart. Journ. Geol. Soc.*, vol. xvii.

the Palæozoic rocks rise out of it into hills or mountains, the New Red Sandstone sweeps round their margin with a flat or gently undulating surface. In many cases the New Red Sandstone ends abruptly against the Palæozoic ground, either from having been deposited against a cliff of the older rocks, or from its having been made to abut against them by subsequent large dislocations. The New Red Sandstone thus surrounds the great Pennine chain of the north of England, from Lancashire through Cheshire into Shropshire, Staffordshire, Leicestershire, and Nottinghamshire, and runs down the vale of York to the coasts of Durham. It bounds, in the same way, the Palæozoic rocks of Wales from the mouth of the Dee to that of the Severn, and runs thence through Somerset and Devon to the mouth of the Exe.

If we draw a slightly sinuous line from the mouth of the Tees through the centre of England to the mouth of the Exe, we should, as remarked by Dr. Buckland in his Bridgewater Treatise, divide England into two totally dissimilar parts, in which the form and aspect of the ground, and the condition and employments of the people, were alike contrasted with each other. The part to the north-west of this line is chiefly Palæozoic ground, often wild, barren, and mountainous, but in many places full of mineral wealth; the part to the south-east of it is Secondary and Tertiary ground, and generally soft and gentle in outline, with little or no wealth beneath the soil. The mining and manufacturing populations are to be found in the first district, the working people of the latter are chiefly agriculturists.

In Ireland the lie and position of the New Red Sandstone are very interesting and characteristic. If the reader will place before him the north-east part of Sir R. Griffith's excellent geological map of Ireland, he will see that the New Red Sandstone is confined to the County Antrim and its immediate borders. If he will follow with his eye the boundary of the formation, he will see all the Palæozoic rocks coming out from underneath it in different places. The metamorphic and granitic rocks, partly covered by Old Red Sandstone, rise from under it in Londonderry, striking north-east and south-west, that strike being continued beneath the New Red Sandstone, as appears by the occurrence of the same rocks in the north-east corner of Antrim, near Cushendall, where the upper rocks have been subsequently removed from them. Farther south, about Dungannon, different portions of the Carboniferous rocks come to the surface from beneath the New Red covering, while along the south-east side of the valley of the Lagan we find the dark slates and grits of the Lower Silurian formation rising from beneath it. Just on the south-east side of Belfast Lough, however, between Cultra and Holywood, the lowest of the Carboniferous rocks appear, resting unconformably on the Lower Silurians, but dipping at a high angle to the north-west beneath the waters of the Lough.

On the opposite shore the New Red Sandstone and superior beds lie, as usual, in a nearly horizontal position. It is clear that the New Red Sandstone of the north-east of Ireland, formerly more extensive than it is now, rests as a great flat cake upon the old surface of the Palæozoic rocks, the beds of which lie beneath that surface in a similarly contorted and greatly denuded condition to that in which they are found outside the New Red Sandstone. The section in Fig. 165 shows in its lower part the undulating beds and the old surface of denudation of the Palæozoic rocks beneath the horizontal beds of the New Red Sandstone. If a shaft were anywhere sunk through these horizontal beds down to that old surface, it is impossible to say, with any hope of correctness, what Palæozoic rock would be the one met with beneath that surface, in that locality. It might be Coal-measures, but might equally well be any one of the other Palæozoic rocks above enumerated, namely—1, The Carboniferous Limestone; 2, the Lower Limestone Shale; 3, the Old Red Sandstone; 4, the Lower Silurian rocks unaltered; or, 5, Mica-schist. The chances, then, would be at least six to one against the probability of Coal-measures with coal being found beneath the part in which the shaft was sunk.

The great practical importance of studying the unconformability of the New Red Sandstone on the Palæozoic rocks below it, and the vast denudation which these rocks suffered before the New Red Sandstone was deposited, cannot be too strongly impressed on the mind of the student. It is one of the chief points in the practical applications of Geology in the British Islands, both for the purpose of guarding against a wasteful expenditure of money in rash enterprises, and for directing it where enterprise may have a chance of being successful.

Foreign Equivalents.

In Germany the Trias is typically divisible into three groups, as follows:—

3. Keuper	1000 feet.
2. Muschelkalk	600 „
1. Bunter Sandstein	1500 „

1. The **Bunter Sandstein**, or "variegated sandstone," is a red and white sandstone interstratified with red marls and thin bands of limestone, sometimes oolitic, sometimes magnesian. This is the "Grès bigarré of the French.

Characteristic Fossils.—*Plants.* Thirty species have been found near Strasbourg; Ferns, Cycads, and Conifers. Among them are Equisetites Mougeotii, Æthophyllum speciosum and Æ. stipulare, Neuropteris elegans, Voltzia heterophylla, Albertia elliptica, Anomopteris.

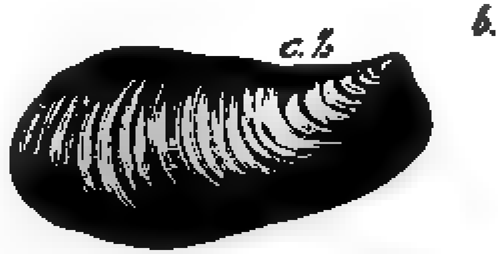
Fish. Acrodus Braunii.

Reptiles. Trematosaurus, Nothosaurus Schimperi, Placodus impressus, footprints of Labyrinthodon.*

* Vogt's *Lehrbuch*, vol. i. p. 383.

2. **Muschelkalk.**—A compact reddish grey, or yellowish limestone, rarely oolitic, but in some places magnesian, especially in the lower beds, which include beds of gypsum and rock-salt. It might accordingly be divided into two sub-groups—

b. Upper Muschelkalk, regularly bedded limestone, more than 300 feet thick.
a. Alternations of limestone, dolomite, marl, and gypsum or anhydrite and rock-salt, 280 feet.



Fossil Group No. 23.—Muschelkalk Fossils.

a. Encrinus liliformis.	*d.* Myophoria vulgaris.
b. Terebratula vulgaris.	*e.* Nautilus hexagonalis or bidorsalis.
c. Avicula (Gervillia) socialis.	*f.* Ceratites nodosus.

Characteristic Fossils.—*Brachiopoda.* Terebratula vulgaris (Foss. gr. 23, *b*).
Echinodermata. Encrinus liliformis (Foss. gr. 23, *a*); Ophiura prisca, O. scutellata.
Conchifera. Gervillia socialis (Foss. gr. 23, *c*); Lima striata; Myophoria vulgaris (Foss. gr. 23, *d*); Ostrea placunoides and O. Schubleri; Pecten discites, P. lævigatus.
Gasteropoda. Turritella reallata.
Cephalopoda. Ceratites nodosus (Foss. gr. 23, *f*); Nautilus hexagonalis (Foss. gr. 23, *e*); N. hirundo.
Fish. Acrodus Gaillardoti; Ceratodus heteromorphus; Hybodus Mougeotii and H. major; Pemphix Suessi; Saurichthys apicalis and costatus.
Reptiles. Nothosaurus; Simosaurus.—(*Vogt.*)

3. **Keuper.**—"Marnes irisées" of the French. Principally red and green marl, but locally divisible into three sub-groups, namely—

c. Keuper Sandstone of a yellowish white, sometimes green and reddish colour, containing Calamites and other plants.

b. Keuper Marls, with gypsum and dolomite, containing coprolites, bones, scales, and teeth of Fish and Saurians.

a. Lettenkohle (clay coal) Group, a dark grey shale or grey sandstone, containing small irregular beds of impure earthy coal, with remains of Mastodonsaurus (Labyrinthodon), Gervillia, Lingula, and Estheria.

This latter group rests directly on the Muschelkalk; and seems, from its animal remains, to belong to it, but its plants are those of the Keuper.

Characteristic Fossils.—*Plants.* Calamites arenaceus; Equisetites; Pterophyllum Jægeri, Pterozamites Münsteri, P. Nilsonii.
Crustacea. Estheria minuta.
Reptiles. Capitosaurus, Mastodonsaurus (Labyrinthodon).
Mammal. Microlestes antiquus.

Near Stuttgart, and in other parts of Germany, the Keuper sandstone is capped by a layer of sandstone breccia, full of the remains of Saurians and Fish in fragments, exactly like that known in England as the Rhætic or Penarth "Bone-bed." A number of beds are described which contain a mixture of fossil forms belonging to Palæozoic and Mesozoic types. Near Hallstatt (south-east of Salzburg), on the north side of the Austrian Alps, and at St. Cassian on the south side, there is a set of beds composed of red, pink, and white marble, from 800 to 1000 feet in thickness, and containing more than 800 species of fossils. These species are mostly peculiar to the Hallstatt and St. Cassian beds, but they belong to genera, some of which are only to be found elsewhere in beds belonging to the Palæozoic rocks, while others are equally confined to beds of Mesozoic age, as is shown in the following table:—

Palæozoic Genera.	Triassic Genera.	Mesozoic Genera.
Cyrtoceras.	Ceratites.	Ammonites.
Orthoceras.	Scoliostoma.	Belemnites.
Goniatites.	Naticella.	Nerinæa.
Loxonema.	Platystoma.	Opis.
Holopella.	Isoarca.	Cardita.
Murchisonia.	Pleurophorus.	Trigonia.
Euomphalus.	Myophoria.	Myoconchus.
Porcellia.	Monotis.	Ostræa.
Megalodon.	Koninckia.	Plicatula.
Cyrtia.		Thecidium.

The first column marks the last appearance of several genera which are characteristic of Palæozoic strata. The second shows those genera which are characteristic of the Upper Trias, either as peculiar to it or as reaching their maximum of development at this era. The third column marks the first appearance of genera destined to become more abundant in later ages.*

Underneath the Hallstatt and St. Cassian beds are others called the Guttenstein and Werfen beds, containing *Ceratites Cassianus, Myacites Fassaensis, Naticella costata,* etc. They consist of—

* Lyell's *Manual*, p. 435.

	Feet.
b. Guttenstein beds, black and grey limestone, alternating with red and green shale	150
a. Werfen beds, red and green shale and sandstone, with gypsum and rock-salt.	

It is yet doubtful whether these are only a lower portion of the St. Cassian beds, or are to be considered as equivalents of the Lower Trias. Over the St. Cassian beds again come 2000 feet of white or greyish limestone, known as the Dachstein beds, and above these 50 feet of grey and black limestone with calcareous marls, called the Kœssen beds, or Upper St. Cassian, by MM. Escher and Merian. Each of these groups contains a peculiar set of fossils of a character which renders it uncertain whether they should be classed as Upper Triassic or as Lower Liassic groups. The Dachstein beds are unfossiliferous below, but the upper portion contains beds entirely made up of Corals (*Lithostrotion*), and others, containing *Hemicardium Wulferi*, *Megalodon triqueter*, and other large bivalves.

The Kœssen beds contain as characteristic fossils *Avicula contorta* and *A. inæquivalvis*, *Pecten Valoniensis*, *Cardium Rhæticum*, *Spirifera Münsteri*, together with many Brachiopoda, some peculiar, a few found in the Lias. According to Mr. Suess, the Kœssen beds correspond to the upper bone-bed of Swabia. It appears most probable that we may class these formations as follows:—

Keuper .	Kœssen or Upper St. Cassian beds. Dachstein beds.
Bunter .	Hallstadt and St. Cassian beds. Guttenstein beds. Werfen beds.

How far the beds may be continuous, or what gaps may be unrepresented among them, remains doubtful. It is possible the Muschelkalk should be intercalated between two of them, and that all these may be merely a few isolated fragments of the series that might have been deposited during a vast imperfectly represented interval.*

* On the classification of the Rhætic beds see Guembel's *Beschreibung der Bayerischen Alpen.*

CHAPTER XXXVI.

JURASSIC OR OOLITIC PERIOD.

THE rocks deposited during this period over the area now occupied by the British Islands were called Oolitic, because in the part where they were first examined and described by Dr. W. Smith, they contained many beds of oolitic limestone. On the Continent they are called Jurassic, because they compose that chain of mountainous hills sweeping round the north-west frontier of Switzerland, which is known by the name of the Jura. As in other cases, we use the designations applied to those two groups of rock as the name also of the period during which they were deposited.

It has been shown in section Fig. 160 that the upper beds of the New Red Sandstone pass underneath some other beds which were called Lias. The red marls of Cheshire and those in the centre of Staffordshire are capped by isolated patches of these beds. Those of county Antrim are similarly covered. If we followed the slightly sinuous line mentioned in the last chapter as running from the mouth of the Tees to that of the Exe, we should find wherever the rocks were exposed that the red marls of the New Red Sandstone dipped

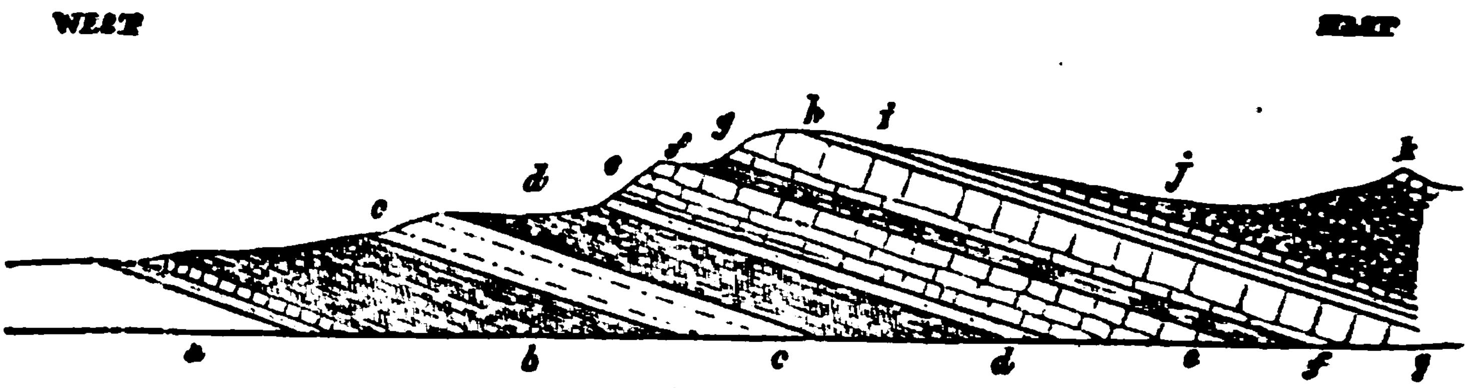


Fig. 161.

Diagrammatic Section of the Gloucestershire Oolites.

	Feet.		Feet.
k. Coral Rag	50	*f.* Fuller's Earth	50
j. Oxford Clay	500	*e.* Inferior Oolite	236
i. Cornbrash	15	*d.* Upper Lias Sand and Shale	300
h. Forest Marble	40	*c.* Marlstone	200
g. Great Oolite	200	*b.* Lower Lias Shale	600

a. Red marls (Top of New Red Sandstone).

gently to the east or south-east, and were in that direction covered by beds of dark clay or shale forming the base of the Lias. Fig. 161 is

a diagrammatic representation of a section through the Oolitic series as it occurs in Gloucestershire, in the neighbourhood of Cheltenham and the Cotteswold Hills. It is based on Sheet 59 of the Horizontal Sections of the Geological Survey, drawn by Mr. Hull, and Sheet 14, drawn by Professor Ramsay and Mr. Bristow. The thicknesses of these different groups are the maximum thicknesses attained in different parts of the section (No. 59) above mentioned; some variations taking place within the limits of that section itself, which is more than thirty miles long, and still greater changes occurring in other districts.

Fig. 162 is a diagrammatic section based on Sheets 20 and 56 of the Horizontal Sections of the Geological Survey, both drawn by Mr. Bristow, across parts of Dorsetshire, through the headlands of Portland and Purbeck. It shows the continuation of the series from the Oxford clay and Coral rag, given in Fig. 161, through the upper part of the Oolites into the Wealden beds, which are the lower part of the

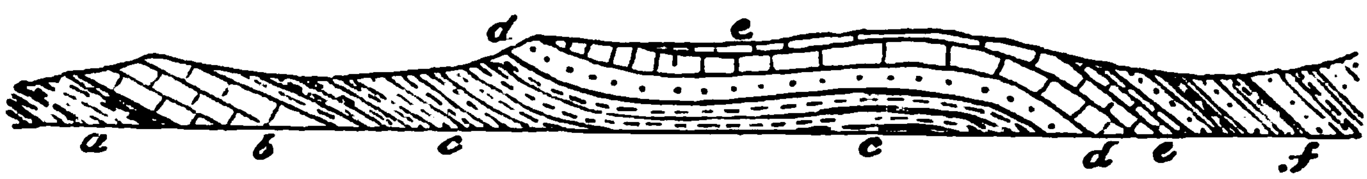


Fig. 162.

Diagrammatic Section of the Dorsetshire Oolites.

	Feet.		Feet.
f. Wealden Sands and Clays .	1400	*c.* Kimeridge Clay . . .	550
e. Purbeck beds	196	*b.* Coral Rag	300
d. Portland Stone and Sands .	230	*a.* Oxford Clay	600

Cretaceous series above. By the examination of these, and many other similar sections in the above-named counties and their neighbourhood, we are enabled to construct the following table of the succession of rock-groups in this district. By studying the relations of these rock-groups to each other, and a comparison of the organic remains contained in them, we are also enabled to throw some of them together into larger groups which have a wider range; while, on the other hand, by examination of each group in any particular locality, we may subdivide it into smaller sets of beds that are only to be recognised in that particular locality. The thicknesses assigned may be taken as the maxima in different places:—*

	Feet.		Feet.
14. Purbeck beds .	150		
13. Portland Beds .	170	*D.* **Portland or Upper Oolites** .	920
12. Kimeridge Clay	600		
11. Coralline Oolite (Coral Rag) . .	250	*C.* **Oxford or Middle Oolites** .	850
10. Oxford Clay .	600		

* The thicknesses are taken from the *Survey Memoirs;* Bristow in *Dawson's Hand-book;* Hull on *Thinning out of Strata,* etc.

	Feet.		Feet.
9. Cornbrash	40		
8. Forest Marble	500		
7. Great Oolite	130		
6. Fuller's Earth	400	*B.* **Bath or Lower Oolites**	1450
5. Inferior Oolite	230		
4. Sands	150		
3. Upper Lias	400		
2. Marlstone	200	*A.* **The Lias**	1200
1. Lower Lias	600		

It would not be an unnatural classification of the rock-groups if we were to take the *Lias*, the *Oxford Clay*, and the *Kimeridge Clay*, as the three great clay deposits of the series, each capped by a variable and minor group of sands and limestones, the Lias forming the base of the Lower Oolites, the Oxford Clay the base of the Coral Rag, and the Kimeridge Clay the base of the Portland Oolites. The Purbeck beds were at one time grouped with the Wealden beds above them—and the Wealden group was separated from the Cretaceous series—an arrangement that is not without good arguments in its favour.

A. The Lias.

This formation is essentially a great clay deposit, with numerous bands of a peculiar argillaceous limestone in its lower part, and a calcareo-argillaceous sandstone near the middle, with blue clay above it, and a loose sandy deposit at top, connecting it with the Inferior Oolite group above.

1. **Lower Lias.***—The Lower Lias is mainly composed of alternating bands of bluish-grey argillaceous and earthy limestone, and laminated clay or shale yielding numerous remains of reptiles, fish, molluscs, and corals. It has been separated by palæontologists into five zones, characterised by the occurrence of particular Ammonites, which are associated with certain assemblages of fossils more or less distinctive of each zone. In the West of England, where the Lias has in some instances been deposited on the upturned edges of the Carboniferous Limestone or other Palæozoic rocks, the lower beds of limestone exhibit an appearance which they do not display where they occur in the regular order of succession above the Triassic series. The limestones differ in lithological character from the same beds elsewhere, and become harder

* Of late years much discussion has taken place, both in this country and on the Continent, concerning the relations of the various beds at the base of the Lias, described in the last chapter. While some authors incline to the separation of these strata as a series intermediate between the Lias and Trias, under the names of "Zone of *Avicula Contorta*," "Rhætic," or "Penarth Beds" (see Wright, *Quart. Journ. Geol. Soc.*, vol. xvi. p. 374. Moore, *Ibid.* vol. xvii. p. 483, etc.), others consider them as forming the true base of the Lias formation, and the names of "Infra-Lias," "Hettangian," and "Lias-conglomerate" have been suggested for the whole or a part of these beds. (See Duncan, *Quart. Journ. Geol. Soc.*, vol. xxiii. p. 12; Bristow, *Ibid.* p. 199; Tate, *Ibid.* 365.)

and more close-grained; the clays and shales are almost entirely absent, and the beds are often conglomeratic. This change is very marked in South Wales. These lower beds may be well seen and studied on the coast of Glamorganshire, in the cliffs under Sutton and Southerndown. They were noticed by Sir Henry T. De la Beche, under the name "Lias Conglomerate," and have since been worked out in detail and mapped by Mr. H. W. Bristow. Similar beds also occur in places on the Mendip Hills, near Wells and Shepton Mallet, where they have been mapped by Mr. H. B. Woodward.*

The limestones of the Lower Lias are extensively quarried for flags and building-stone, besides being burned for lime. The Lias of Lyme Regis, and other places, furnishes a hydraulic cement, which is in great request.

2. **The Marlstone** is a well-marked division of the Lias, being more arenaceous than the rest of the formation, and often bound by calcareous or ferruginous cement into a hard stone. In Gloucestershire it is divisible into the hard "rock-bed" above, and the sands, often rather argillaceous, below. It frequently contains bands of ironstone, which have of late years been largely quarried both in the north and south of England. The immense deposits of iron-ore, now so extensively worked in the district of Cleveland in North Yorkshire, are of this age.

3. **Upper Lias.**—This consists of a great thickness of blue clay, over which are some brown and yellow sands, which were classed with the Inferior Oolite, until separated from it on good palæontological evidence by Dr. Wright of Cheltenham,† who gave them the name of Upper Lias Sands. These are capped by a particular band called the "Cephalopoda bed," from the abundance of those fossils which it contains. Dr. Lycett and some other geologists, however, consider these beds as intermediate in age between the Lias and the Inferior Oolite.‡ The Upper Lias Clay, which is in some places 400 feet thick, thins out towards the south, so that at Uley Bury it is only 70 feet thick, and at Lansdown, near Bath, it seems to have disappeared altogether.§

Characteristic Fossils of the Lias.—Each of the subdivisions of the Lias just described has a peculiar assemblage of fossils characteristic of it in the district where its separation from the rest is obvious. Even the Upper Lias Sand may be distinguished palæontologically from the Upper Lias Clay in the Gloucestershire district, and has been so separated by Dr. Wright and Mr. Lycett. These subdivisions have more than a local interest, inasmuch as they point distinctly to changes in

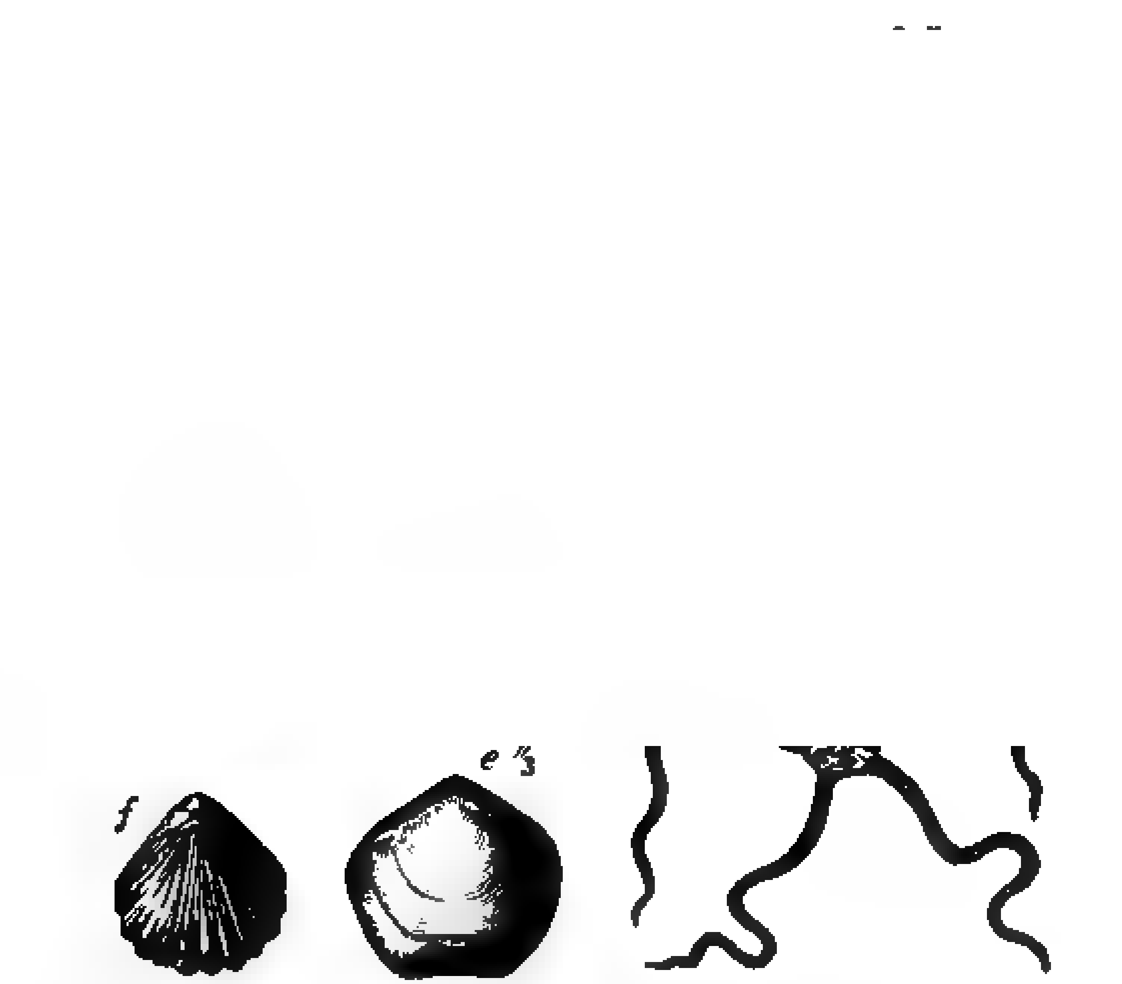
* See *Mem. Geol. Surv.*, vol. i.; and papers by C. Moore, P. M. Duncan, H. W. Bristow, in the *Quart. Journ. Geol. Soc.*, vol. xxiii.

† Wright on "Upper Lias Sands," *Quart. Journ. Geol. Soc.* vol. xii.

‡ *Ann. and Mag. Nat. Hist.*, September 1857. Handbook to Cotteswold Hills, etc.

§ Sheet 14, Horizontal Sections of the Geological Survey, Messrs. Ramsay and Bristow.

the forms of life, and therefore to vast lapse of time during the deposition of the beds. The limits of this work, however, do not admit of the details necessary to give a complete account of these subdivisions, for which I must refer the student to the works of Quenstedt and Oppel, and to Dr. Wright's papers in the *Quarterly Journal of the Geological*



Fossil Group No. 24.
Lias Fossils.

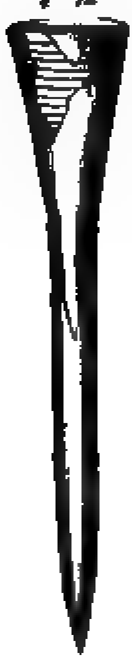
a. Otopteris obtusa.
b. Extracrinus Briareus.
c. Ophioderma Egertoni.
d. Spirifera Walcottii.
e. Terebratula numismalis.
f. Rhynchonella rimosa.

*Society.** This great abundance of fossils in the Lias makes it difficult to select any short list of species which may be considered more characteristic of the formation than many others that might be mentioned. The following, however, would probably be included in any list :—†

* Quenstedt, "Der Jura;" Oppel, "Juraformation." Wright, *Quart. Jour. Geol. Soc.*, vol. xvi. p. 374, etc.

† The letters L, M, and U, indicate that the species occur in the Lower, Middle, or Upper Lias respectively.

Plants . . .	Equisetites Brodiei, L. . .	Q. J. G. S. vi., p. 414.
	Otopteris obtusa, L. . .	Foss. gr. 24, *a*.
	Palæozamia Bechei and P. Bucklandi, L. . . .	Geol. Tr. i., t. 7.
Foraminifera	Polymorphina Liassica, L. and M.	Q. J. G. S. ii., p. 80.
	Spirilina infima, L. . .	*Ibid.*
Actinozoa . .	Theococyathus Moorei, L. .	Pal. Soc. Foss. Cor.*
	Isastrea Murchisoni.	
	Montlivaltia cuneata, M.	
Brachiopoda .	Leptæna Moorei, U. . .	Lyell's Man., fig. 441.
	Rhynchonella rimosa, M. and L.	Foss. gr. 24, *f*.
	——— tetrahedra, M. .	Tab. View.
	Spirifera Walcottii, M. and L.	Foss. gr. 24, *d*.
	Terebratula numismalis, M. and L.	*Ibid.* 24, *e*.
Conchifera .	Avicula cygnipes, M. and L. .	Tab. View.
	Monotis decussata, L. . .	Foss. gr. 25, *a*.
	Cardinia Listeri, M. and L. .	Tab. View.
	Gryphæa incurva, L. . .	Foss. gr. 25, *b*.
	Ostrea Liassica, L.	



Fossil Group No. 25.

Lias Fossils.

a. Avicula decussata.
b. Gryphæa incurva.
c. Hippopodium ponderosum.
d. Pleurotomaria Anglica.
e. Belemnites elongatus.
f. Ammonites communis.

* Palæontographical Society, Fossil Corals.

Conchifera .	Pecten Liassicus, M.	
	Hippopodium ponderosum, L.	Foss. gr. 25, *c.*
	Lima (Plagiostoma) gigantea, L.	Tab. View, and Lyell's Man., fig. 437.
	Modiola scalprum, M. . .	Phillips's Man., fig. 205.
Gasteropoda .	Pholadomya ambigua, U. M. L.	Sow. M. C., t. 227.
	Pleurotomaria Anglica, M. and L.	Foss. gr. 25, *d.*
Cephalopoda .	Ammonites bifrons, U. .	Tab. View.
	——— Bucklandi, L .	
	——— communis, U. .	Foss. gr. 25, *f.*
	——— heterophyllus, U.	Tab. View.
	——— obtusis, L. .	*Ibid.*
	——— planorbis, L.	
	——— serpentinus, U. .	*Ibid.*
	——— capricornis, M	
	——— spinatus, M.	
	Belemnites elongatus, M. .	Foss. gr. 25, *e.*
	——— tubularis, U. .	Tab. View.
	Nautilus truncatus, L. . .	*Ibid.*
Echinodermata	Extracrinus Briareus . .	Foss. gr. 24, *b.*
	Ophioderma, M. . . .	*Ibid.* 24, *c.*
	Uraster Gaveyi, M . . .	M. G. S., Dec. 3.
	Acrosalenia minuta, L. . .	Pal. Soc. Mon.
	Cidaris Edwardsii, M. . .	
Crustacea . .	Eryon antiquus . . .	Chart of Crustacea.
	——— Barrovensis . .	*Ibid.*
	Glyphæa Liassica . . .	*Ibid.*
Insecta . .	Coleoptera (Elytra and wings).	
	Neuroptera (Libellula Hopei, etc.)	
Fish . . .	Acrodus nobilis, L. . .	Lyell's Man., fig. 453.
	Æchmodus Leachii, L. . .	*Ibid.* 452.
	Dapedius politus, L. . .	Tab. View.
	Hybodus reticulatus, L. .	Lyell's Man., fig. 454.
Reptiles . .	Ichthyosaurus * communis, L.	Tab. V. and Lyell's Man., etc.
	Plesiosaurus dolichodeirus, L.	*Ibid.* *Ibid.*
	Dimorphodon macronyx, L. .	Geol. Trans. vol. iii.
	Teleosaurus Chapmanni, L.	

B. The Lower Oolites.

4. **The Inferior Oolite** comprises those beds which come next above the Cephalopoda bed of the Upper Lias Sands, and thus form the lowest group of the Lower Oolites. According to the data given in Sheet 59 of the Horizontal Sections of the Geological Survey, it is in the hills to the north-east of Cheltenham, to be subdivided into—

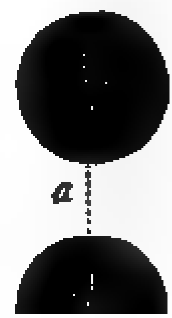
	Feet.
e. The Ragstone . .	40
d. Upper Freestone . .	34
c. Oolite Marl . . .	7
b. Lower Freestone . .	147
a. The Pea Grit . .	38

* Most manuals give figures of Ichthyosauri, Plesiosauri, Pterodactyli, etc.; see especially Buckland's *Bridgewater Treatise*, etc., and Mr. Waterhouse Hawkins's Diagrams.

The *Pea Grit* is a pisolitic limestone, consisting of a number of flat concretions like large flattened peas. The *Freestones* are fine-grained, pale, oolitic, or shelly limestones, containing near the top a seven-foot bed of brown marl, *c*, with an imperfect oolitic structure. The *Ragstone* is a brown sandy limestone, sometimes hard and firm, at others incoherent. In this neighbourhood even these subdivisions have their characteristic fossils. As we recede from this neighbourhood, however, these subdivisions naturally die out and disappear; other beds of coarse limestone, sometimes oolitic, and sometimes sandy, taking their place.

In Oxfordshire, according to Professor Phillips, the whole group of the Inferior Oolite disappears, neither the beds nor the peculiar fossils

x



Fossil Group No. 26.

Inferior Oolite Fossils.

a. Anabacia hemispherica.
b. Rhynchonella spinosa.
c. Ostrea flabelloides.
d. Pholadomya fidicula.
e. Pleurotomaria ornata.
f. Ammonites Humphresianus.

being discoverable. In North Northamptonshire and Lincolnshire, however, the formation reappears under the form of a white limestone, often attaining a great thickness, and affording many well-known and valuable building stones, as those of Ancaster, Ketten, Barnack, etc. The Collyweston slate forms the base of this limestone series, which is

underlaid by thick strata of sand and brown ironstone, the latter being now extensively dug for smelting. The whole of these beds disappear in South Yorkshire under the overlapping Upper Cretaceous rocks, but are again seen, with somewhat different characters, in North Yorkshire.*

Characteristic Fossils of the Inferior Oolite.

Actinozoa . .	Anabacia hemispherica . .	Foss. gr. 26, *a*.
	Montlivaltia trochoides . .	Pal. Soc. Foss. Cor.
Brachiopoda .	Rhynchonella spinosa . .	Foss. gr. 26, *b*.
	Terebratula carinata . .	Pal. Soc. Dav. Brach.†
	——— fimbria . .	Tab. View.
	——— perovalis . .	*Ibid.*
Conchifera .	Astarte elegans . . .	*Ibid.*
	Gresslya abducta . . .	Phill. G. Y. i., t. 11.
	Lima pectiniformis (proboscidea)	Tab. View.
	Ostræa flabelloides . .	Foss. gr. 26, *c*.
	Pecten dentatus . . .	Sow. M. C. 574.
	Pholadomya fidicula . .	Foss. gr. 26, *d*.
Gasteropoda .	Chemnitzia lineata . .	Sow. M. C. 218.
	Pleurotomaria elongata . .	*Ibid.* 193.
	——— ornata . .	Foss. gr. 26, *e*.
	——— pallium . .	Sow. M. C. 221.
Cephalopoda .	Ammonites Brocchii . .	*Ibid.* 202.
	——— Brodiei . .	*Ibid.* 351.
	——— Brongniartii . .	Phillips's Man., fig. 238.
	——— Humphresianus .	Foss. gr. 26, *f*.
	——— Murchisonæ . .	Sow. M. C. 550.
	——— Parkinsoni . .	Tab. View.
	Etc. etc.	
	Belemnites ellipticus . .	Geol. Trans. ii. t. 8.
	Nautilus sinuatus . . .	Sow. M. C. 194.
Echinodermata	Collyrites ringens . . .	Tab. View.
	Echinus perlatus . . .	*Ibid.*
	Nucleolites Agassizii . .	Ann. Nat. Hist. 1852.
Fish . . .	Pholidophorus Flesheri . .	Agassiz.
	Strophodus subreticulatus .	

5. The Fuller's Earth.—Above the Inferior Oolite comes, in the Gloucestershire district, a series of blue and yellow shales, clays, and marls. The peculiar kind of clay called Fuller's Earth, which has given the name to the group, occurs at the base of the Great Oolite, in the downs immediately south of Bath, where it was largely extracted some years ago for the use of the cloth manufacturers of the district.

Towards the middle part of the Fuller's Earth clay, south of Bath, are beds of cream-coloured earthy limestone, to which the name Fuller's Earth Rock is generally given. The limestones, which are never oolitic, contain numerous fossils, amongst which *Ostræa acuminata* may be mentioned as being very abundant.

The maximum thickness of the Fuller's Earth in the Gloucester-

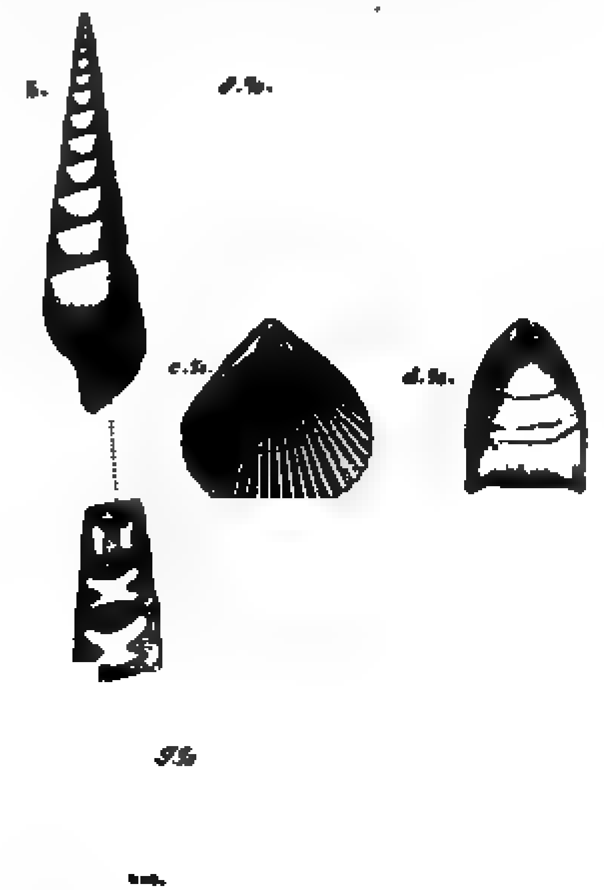
* See p. 634.

† Palæontographical Society, Davidson's *Brachiopoda*.

shire district is about 150 feet, rather rapidly diminishing northwards and eastwards, in which directions it soon disappears. In Dorsetshire, however, the formation includes 400 feet of strata.*

Characteristic Fossils.—None, unless the little oyster called *Ostrea acuminata* (*Tabular View* and *Lyell's Manual*, fig. 424); the other fossils contained in this group, such as *Terebratula ornithocephala*, and some others, are a mixture of Inferior Oolite and Great Oolite species.

6. Great or Bath Oolite.—This, like the other Oolitic groups, except the clays, has a very variable lithological character. Mr. Lycett says that near Minchinhampton it is made up of weatherstones, sandstones,



Fossil Group No. 27.
Great Oolite Fossils.

a. Pterophyllum comptum.
b. Hemicidaris minor.
c. Rhynchonella concinna.
d. Terebratula digona.
e. Lima cardiiformis.
f. Trigonia Goldfussii.
g. Purpuroidea Morrisii.
h. Nerinæa Voltzii.

and limestones; the weatherstones (shelly calcareous sandstones) being always at the base of the group, but passing laterally into sandstones,

* Mr. R. Tate argues, on palæontological grounds, that the Fuller's Earth should be regarded as the top of the Inferior Oolite rather than the base of the Great Oolite. (*Quart. Journ. of Science*, Jan. 1, 1870.)

which are commonly covered by limestones, while the weatherstones have never any of the limestones above them.*

Mr. Hull divides the Great Oolite near Cheltenham into two zones. *a.* The Lower zone, a variable series of sandy flags, "slates," and blue limestones, with white oolitic freestones, showing much oblique lamination. The flaggy limestones, and sometimes the thick-bedded ones, split in some places into very thin slabs, which are called, though erroneously, "slates." The Stonesfield Slate, so celebrated for its terrestrial reptiles and mammalian remains, belongs to these beds, and might therefore give its name to the zone. Its average thickness is 50 feet. *b.* The Upper zone is well marked in Gloucestershire, by the occurrence of beds of white marl at its base, and white thick-bedded limestone at its summit. Its thickness is 150 feet.†

Characteristic Fossils of the Great Oolite.

Plants . .	Equisetum columnare . .	Phillips's Man., fig. 218, and Mantell's Meds., fig. 13.
	Pterophyllum comptum . .	Foss. gr. 27, *a.*
	Tæniopteris latifolia . .	Mantell's Meds., fig. 26.
	——— vittata . . .	Phillips's Man., fig. 217.
	Thuytes expansus . . .	Phill. G. Y. i., t. 10.
Actinozoa . .	Isastræa Conybeari . . .	Pal. Soc. Foss. Cor.
Brachiopoda ‡	Rhynchonella concinna . .	Foss. gr. 27, *c.*
	Terebratula coarctata . .	Tab. View.
	——— digona . . .	Foss. gr. 27, *d.*
	——— maxillata . .	Tab. View.
Conchifera .	Arca Hirsonensis . . .	Phill. G. Y., t. 11, fig. 43.
	Gervillia lanceolata . . .	Tab. View.
	Lima cardiiformis . . .	Foss. gr. 27, *e.*
	Pachyrisma grande . . .	Pal. Soc. Ool. Biv.
	Pholadomya acuticosta . .	Tab. View.
	Pteroperna costatula . .	Pal. Soc. Ool. Biv.
	Trigonia Goldfussii . . .	Foss. gr. 27, *f.*
	——— impressa . . .	Tab. View.
Gasteropoda .	Alaria atractoides . . .	Pal. Soc. Ool. Foss.
	Cylindrites acutus . . .	Lyell's Man., fig. 406.
	Nerinæa Voltzii § . . .	Foss. gr. 27, *h.*
	Patella rugosa . . .	Lyell's Man., fig. 407.
	Purpuroidea Morrisii . .	Foss. gr. 27, *g.*
	Trochotoma annuloides . .	Pal. Soc. Ool. Foss.
Cephalopoda .	Ammonites gracilis . . .	Pal. Soc. Ool. Mol.
	Belemnites fusiformis . .	Tab. View.
	——— Waterhousei.	
	Nautilus Baberi . . .	Pal. Soc. Ool. Mol.
Echinodermata	Hemicidaris minor . . .	Foss. gr. 27, *b.*

* *Quart. Journ. Geol. Soc.*, vol. iv.; and *Mem. Pal. Soc.*, 1850.

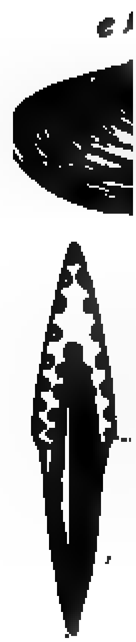
† Geology of Cheltenham, *Mem. Geol. Surv.*, 1857.

‡ Messrs. Lycett and Morris have published the Mollusca of the Great Oolite in the volumes of the Palæontographical Society, referred to in the succeeding pages.

§ The lower figure shows a section of the shell.

Echinodermata	Pseudodiadema pentagonum .	Pal. Soc. Brit. Ech.*
Fish . . .	Asteracanthus semisulcatus .	Agassiz's Fossil Fish.
	Pholidophorus minor . .	Agassiz's Fossil Fish.
	Strophodus magnus . . .	Agassiz's Fossil Fish.
Reptiles . .	Megalosaurus Bucklandi . .	Mantell's Meds., ch. xvii.
Mammalia .	Amphitherium Prevostii . .	Lyell's Man., fig. 412.
	Phascolotherium Bucklandi .	*Ibid.*, fig. 419.
	Stereognathus Ooliticus . .	Q. J. G. S., vol. xiii.

7. **The Cornbrash and Forest Marble Group.**—This is a very variously composed set of clays, sands, and limestones, containing local sub-



Fossil Group No. 28.

Cornbrash and Forest Marble Fossils.

a. Acrosalenia hemicidaroides.
b. Apiocrinus Parkinsoni.
c. Terebratula intermedia.
d. Gresslya peregrina.
e. Myacites decurtata.
f. Pholadomya lyrata.
g. Ammonites discus.

divisions such as the Bradford Clay, the Forest Marble, and the Cornbrash itself.

The Bradford Clay is a blue unctuous clay occurring at Bradford, in

* *British Fossil Echinodermata*, by Dr. T. Wright.

Wiltshire, and extending for a few miles around it; it is never more than forty or fifty feet in thickness; locally full of *Apiocrinites Parkinsoni* (*rotundus*). Foss. gr. 28, *b*.

The Forest Marble (so named from Wychwood Forest, in Oxfordshire, where it is 30 feet thick) is composed of coarse fissile oolite, with much oblique lamination, hard shelly limestones, blue marls and shales, yellow siliceous sand, with large spheroidal blocks of limestone, and fine oolitic freestone. It is rarely more than 40 feet thick in the Gloucestershire district, but in Dorsetshire is said by Mr. Bristow* to be 450 feet thick.

The Cornbrash is generally a rubbly, somewhat ferruginous limestone, in thin beds. In the Midland districts of England it is never more than 15 feet thick, but in Dorsetshire it reaches to about 40 or 50 feet,† and is remarkably fossiliferous, *Avicula echinata* and *Nucleolites clunicularis* being abundant and characteristic.

Characteristic Fossils of the Cornbrash and Forest Marble Group.

Brachiopoda .	Terebratula intermedia . .	Foss. gr. 28, *c*.
	———— obovata . . .	Tab. View.
Echinodermata	Acrosalenia hemicidaroides .	Foss. gr. 28, *a*.
	Apiocrinus Parkinsoni . .	*Ibid.* 28, *b*.
	Nucleolites clunicularis . .	Tab. View.
Annelida . .	Serpula tetragona . . .	Sow. M. C., 599.
Conchifera .	Avicula echinata . . .	Tab. View.
	Ceromya concentrica . . .	Sow. M. C. 491.
	Gresslya peregrina . . .	Foss. gr. 28, *d*.
	Isocardia minima . . .	Tab. View.
	Lima rigidula	Phill. G. Y., t. 7.
	Modiola bipartita . . .	*Ibid.* t. 4.
	Myacites decurtata . . .	Foss. gr. 28, *e*.
	——— securiformis . .	Phill. G. Y., t. 7.
	Pecten fibrosus	*Ibid.* t. 6.
	Pholadomya deltoidea . .	Sow. M. C. 197.
	———— lyrata . . .	Foss. gr. 28, *f*.
Gasteropoda .	Chemnitzia vittata . . .	Phill. G. Y., t. 7, fig. 15.
Cephalopoda .	Ammonites discus . . .	Foss. gr. 28, *g*.
Fish . . .	Asteracanthus acutus . .	Ag. foss. fish.
	Cardiodon rugulosus.	

The Lower Oolites of Yorkshire.—The beds which lie between the Lias and the Oxford Clay preserve the structure above given, with more or less constancy, from Somersetshire into Lincolnshire, forming a continuous ridge, with an unbroken escarpment, till we reach the estuary of the Humber. A little north of that river the whole Oolitic series, with the exception of the Lias, is overlapped and concealed by the beds of the Cretaceous series, from underneath which, however, they gradually reappear again farther north, and the Lower Oolites rise

* Dawson's *Handbook to the Geology of Weymouth*, with vertical section by Mr. Bristow.

† *Ibid.*

from beneath the Oxford Clay into some wild hills called the Yorkshire Moorlands, which end in precipitous cliffs along the coast about Whitby and Scarborough.

In this district the changes, often apparent as we trace the Lower Oolites from Somerset into Lincolnshire, are found to have been still further carried out, so that, instead of the groups just described, we get the following section, which is condensed from Professor Phillips's descriptions :—*

	Feet.
5. Shelly Cornbrash, limestone of Gristhorp and Scarborough . .	10
4. Sandstones, shales, ironstones, and coals of Gristhorp, Scarborough, and Scalby, enclosing some calcareous shelly bands . . .	200
3. Shelly oolite, and clays of Cloughton and West Nab ("Grey limestone of Scarborough")	30
2. Sandstones, shales, ironstones, and workable coal of the Peak, Stainton Dale, and Haiburn Wyke.	500
1. Irony sandstone and subcalcareous beds, with bands of shells and plants ("Dogger")	70

It is singular that the little insignificant-looking band called Cornbrash is persistent throughout the whole of England, though it undergoes considerable modifications in lithological and palæontological characters, while such great changes take place in the more important beds above and below. The "grey-limestone," with the beds below it, are now usually referred, on palæontological evidence, to the Inferior Oolite. The upper part of the "Dogger" belongs to the same formation; its lower part to the stone called "Upper Lias Sand."

The *Characteristic Fossils* of the Lower Oolites of Yorkshire are principally plants, many of which are ferns. The following genera may be mentioned, some of which have different species in these beds and in the Carboniferous formation, while those marked with one asterisk are only Mesozoic, and those with two exclusively Oolitic genera. Some of the Equisetites are found erect; and we have here an imperfect coal formation of the Oolitic period, the coals of which only differ from those of the Carboniferous formation in quantity and economic value.

Cyclopteris, Equisetites, **Otopteris, **Pachypteris, **Palæozamia, Pecopteris, **Phlebopteris, *Pterophyllum, **Sagenopteris (Glossopteris), Sphenopteris, **Tæniopteris, *Thuytes, **Zamites.

C. The Oxford or Middle Oolites.

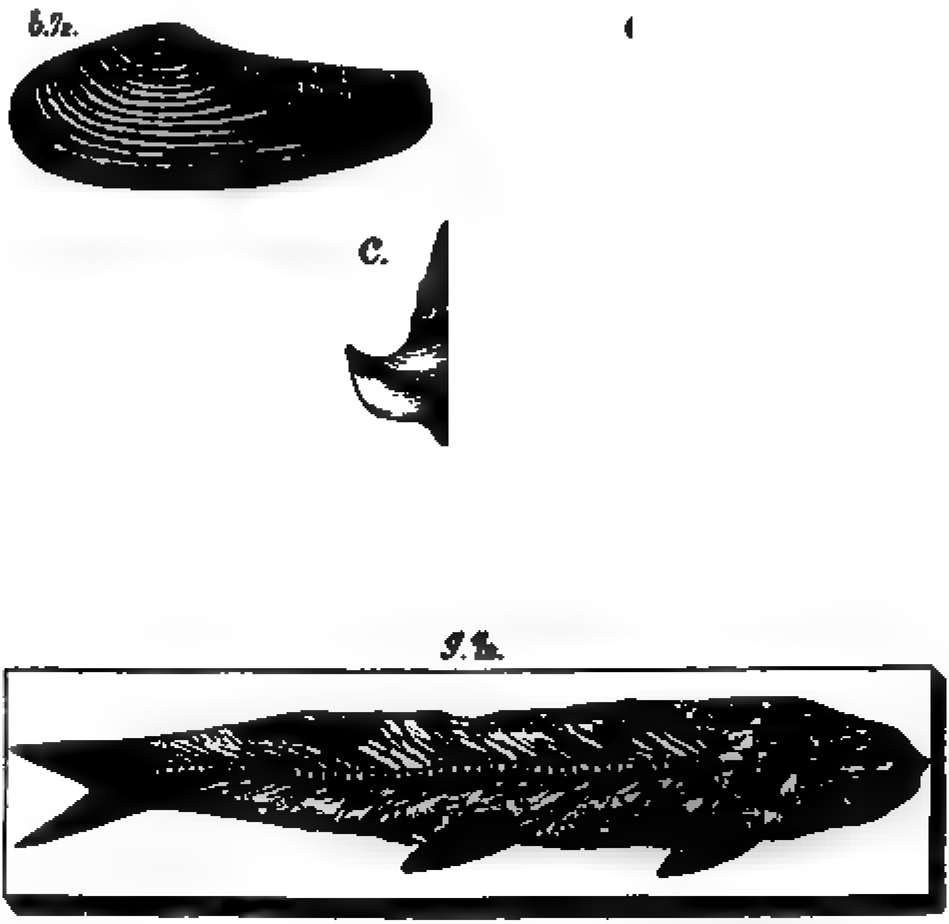
This division comprises the Oxford Clay and the Coral rag groups—

8. The Oxford Clay is so called as lying beneath the plain on which Oxford stands, but it extends across England from Weymouth in Dorset to Filey Bay in Yorkshire. It is generally a dark blue clay, sometimes dark grey, approaching to black, and occasionally, as at

* *Quart. Journ. Geol. Soc.* vol. xi. p. 84.

Weymouth, it contains numerous septarian nodules. In its lower portion it has occasionally some beds of tough calcareous sandstone, with brown sands, called Kelaways Rock, from a place in Wiltshire. This Kelaways Rock appears to be wanting in the Midland counties as a distinct rock, though its peculiar fossils occur in the lower part of the Oxford clay. It reappears in Yorkshire with the same characters and fossils as in the south. The maximum thickness of the Kelaways Rock is 80 feet; that of the whole Oxford Clay, including it, cannot be less in some places than 600 feet.

Characteristic Fossils of the Oxford Clay.—The fossils of the Oxford clay are numerous, and often very beautiful, the shells frequently retaining their irridescence from having been packed in close clay, or



Fossil Group No. 29.

Characteristic Fossils of the Oxford Clay.

a. Gryphæa dilatata.
b. Anatina undulata.
c. Alaria composita.
d. Ammonites Jason.
e. Ammonites excavatus.
f. Belemnites hastatus.
g. Leptolepis macrophthalmus.

being converted, like those in the Lias, into brilliant iron pyrites. The following list includes a few of the most common species:—

Annelida . .	Serpula vertebralis . . .	Sow. M. C. 599.
Crustacea . .	Megacheirus Pearcei . . .	Ann. Nat. H., 1849.
	Pollicipes concinnus . . .	Sow. M. C., 647.
Conchifera .	Anatina undulata . . .	Foss. gr. 29, *b*.
	Astarte lurida	Phill. G. Y., t. 5, fig. 2.
	Gryphæa dilatata . . .	Foss. gr. 29, *a*.
	Myacites recurva . . .	Phill. G. Y., t. 5, fig. 25.
	Ostræa undosa	*Ibid.* t. 6, fig. 4.
Gasteropoda .	Alaria composita . . .	Foss. gr. 29, *c*.
Cephalopoda .	Ammonites Calloviensis . .	Tab. View.
	———— cordatus . .	*Ibid.*
	———— excavatus . .	Foss. gr. 29, *e*.
	———— Jason . . .	*Ibid.* 29, *d*.
	———— Lamberti . .	Sow. M. C. 242.
	———— modiolaris (sublævis)	Tab. View.
	Belemnites hastatus . . .	Foss. gr. 29, *f*.
	———— Puzosianus * . .	Tab. View and Ly. Man.
	Nautilus hexagonus . . .	Tab. View.
Fish . . .	Aspidorhynchus euodus . .	Q. J. G. S. vol. i. p. 231.
	Lepidotus macrocheirus . .	*Ibid.*
	Leptolepis macrophthalmus .	Foss. gr. 29, *g*.

9. **The Coralline Oolite** was so called from the abundance of corals contained in its lower beds in some parts of Oxfordshire and Wiltshire. Like all the other calcareous or arenaceous groups of the Oolite, this is very irregular, and subject to great variations in character and thickness. There is a pretty close general resemblance in the Yorkshire and Wiltshire types, while in the intermediate district the whole group seems to disappear. It may be divided into three sub-groups—

	Feet.
c. Upper Calcareous Grit, maximum thickness	60
b. Coral Rag ,, ,, ...	60
a. Lower Calcareous Grit ,, ,, ...	100

a. The lower beds in Yorkshire are a series of grey marly sandstones seventy feet thick, passing up into cherty limestone, covered by sands full of great calcareous concretions, capped by strong calcareous sandstones.

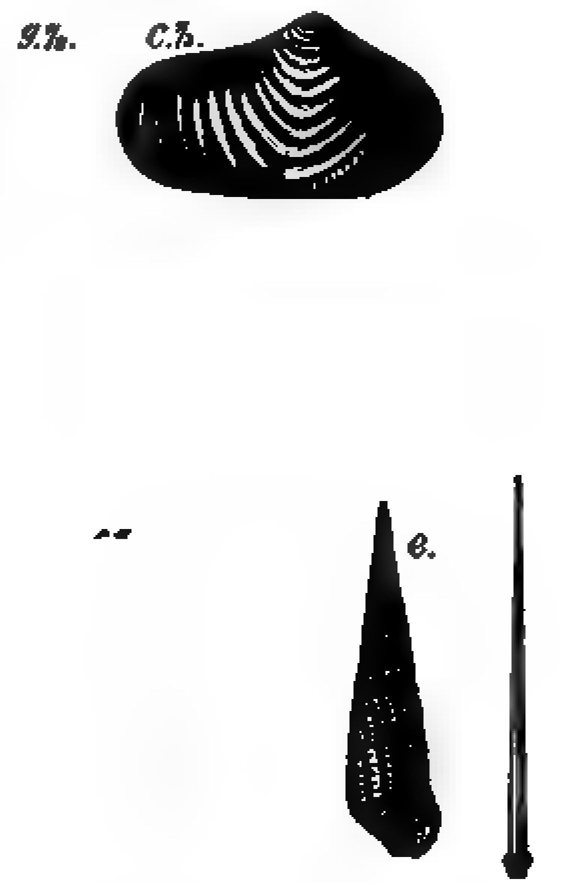
b. A variable group of irregular masses of nodules made of corals compacted together, often earthy, and connected by blue clay, passing into blue crystalline limestone, alternations of hard shelly oolite, and soft perishable limestone, and in Wiltshire a rubbly nodular oolite, sometimes pisolitic.

c. The Upper group, obscurely indicated in the south, is in the north like group *a*, but more ferruginous and less cherty, passing up by intercallation into the Kimeridge Clay above.—(*Phillips*.)

The Coral Rag may be examined in Dorsetshire and Wiltshire, in

* See also Mantell's Medals, Figs. 143 and 144, and description.

Shotover Hill in Oxfordshire, or on the coast of Yorkshire, about Scarborough and Filey. At Shotover Hill, however, considerable erosion



Fossil Group No. 30.—Coralline Oolite Fossils.

a. Thecosmilia annularis.
b. Acrosalenia decorata, with spine.[1]
c. Goniomya literata.
d. Trigonia clavellata.*
e. Cerithium muricatum.
f. Ammonites perarmatus.
g. Belemnites abbreviatus.

of its upper part took place before the deposition of the Kimeridge Clay, all the upper calcareous grit having been removed.—(*Phillips.*)

Characteristic Fossils of the Coralline Oolite.

Plants . . .	Carpolithes Bucklandi . .	Lind. F. F.,† 189.
	——— conicus . . .	*Ibid.*
Actinozoa .	Calamophyllia Stokesii . .	Tab. View.
	Isastræa explanata . . .	*Ibid.*
	Stylina tubulifera . . .	*Ibid.*
	Thamnastræa arachnoides . .	*Ibid.*
	Thecosmilia (Caryophyllia) annularis	Foss. gr. 30, *a.*
Echinodermata	Acrosalenia decorata . .	*Ibid.* 30, *b.*
	Cidaris coronata . . .	Ly. Man. 397.
	——— florigemma . . .	Phill. Man. 242.

* This is a Kimeridge clay and Portland Stone fossil, according to Morris's Catalogue.
† Lindley and Hutton's Fossil Flora.

Echinodermata	Hemicidaris intermedia . .	Tab. V., and Mantell's Meds., Fig. 101.
	Nucleolites scutatus (dimidiatus)	Phill. Man. 244.
Crustacea . .	Glyphæa scabrosa . . .	Phill. G. Y. vol. i. p. 170.
Conchifera .	Goniomya literata . . .	Foss. gr. 30, *c*.
	Lima (Plagiostoma) rigida .	Tab. View.
	Ostræa gregaria . . .	Ly. Man. 393, and Tab. View.
	Pecten vimineus . . .	Sow. M. C. 543.
	Pholadomya æqualis . .	*Ibid.*
	Trigonia costata . . .	Tab. View.
Gasteropoda .	Cerithium muricatum . .	Foss. gr. 30, *e*.
	Chemnitzia Heddingtonensis .	Tab. View.
	Nerinæa Goodhallii . . .	Ly. Man. 395, and Tab. View.
	——— hieroglyphica . .	*Ibid.* 394.
	Phasianella (Chemnitzia) striata	Tab. View.
Cephalopoda .	Ammonites perarmatus . .	Foss. gr. 30, *f*.
	——— vertebralis . .	Tab. View.
	Belemnites abbreviatus . .	Foss. gr. 30, *g*.
Fish . . .	Gyrodus Cuvieri . . .	Ag. Poiss. foss.
	Hybodus obtusus . . .	*Ibid.*

D. The Upper or Portland Oolites.

This division consists of three groups, namely—10. The Kimeridge Clay; 11. The Portland beds; and, 12. The Purbeck beds—the two latter groups being only known in the southern part of England.

10. The Kimeridge Clay is so called from the village of Kimeridge on the coast of Dorsetshire, a little west of St. Alban's Head. It is traceable through Wiltshire and Buckinghamshire, where its maximum thickness is 500 or 600 feet, but it seems to disappear in Bedfordshire, Huntingdon, and Cambridgeshire, probably owing to the overlap of the "Lower Greensand." It is again visible in Lincolnshire, and largely in the Vale of Pickering, in Yorkshire. It is in some places a dark grey shaly clay, in others brownish or yellowish, containing bands of sand or of calcareous grit, or ferruginous oolite, and layers of septaria. In some places, especially in the district about the Isle of Purbeck, it becomes very carbonaceous, and the "bituminous shale" sometimes passes into layers of a kind of brown shaly imperfect coal. Layers of a particular kind of oyster (*Ostræa deltoidea*) occur abundantly in many places, always appearing "in broad continuous floors parallel to the planes of stratification, the valves usually together, with young ones occasionally adherent to them, and entirely embedded in clay, without nodules or stones of any kind, and without any organic remains in the layers."*

Characteristic Fossils of the Kimeridge Clay.

Brachiopoda .	Rhynchonella inconstans .	Foss. gr. 31, *a*.
Conchifera .	Astarte Hartwelliensis . .	*Ibid.* 31, *c*.
	Cardium striatulum . .	Ly. Man. 385.
	Exogyra (Gryphæa) virgula .	Foss. gr. 31, *b*.

* Phillips's *Man.* p. 311.

Conchifera .	Ostræa deltoidea . . .	Ly. Man., 386; Phill. Man. 258, and Tab. View.
	Pinna granulata . . .	Sow. M. C. 347.
	Thracia depressa . . .	Foss. gr. 31, *d.*
	Trigonia clavellata . . .	*Ibid.* 30, *d.*
Gasteropoda .	Chemnitzia gigantea.	
	Patella latissima . . .	*Ibid.* 31, *f.*
	Pleurotomaria reticulata . .	*Ibid.* 31, *e.*
Cephalopoda .	Ammonites biplex . . .	*Ibid.* 31, *g.*
	———— rotundus . .	Sow. M. C. 293.
	———— triplicatus . .	*Ibid.* 92.
Fish . . .	Asteracanthus ornatissimus .	Ag. Poiss. foss.
	Hybodus acutus . . .	*Ibid.*
	Sphærodus gigas . . .	*Ibid.*
Reptiles . .	Ichthyosaurus trigonus . .	Ow. Brit. Ass. Rep.
	Plesiosaurus affinis . .	*Ibid.*
	Pliosaurus (the genus) . .	*Ibid.*
	Stenecosaurus rostro-minor .	*Ibid.*
	Teleosaurus asthenodeirus .	*Ibid.*

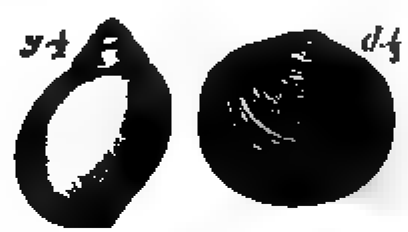
Fossil Group No. 31.—Kimeridge Clay Fossils.

a. Rhynchonella inconstans, and end view of same.
b. Exogyra virgula.
c. Astarte Hartwelliensis.
d. Thracia depressa.
e. Pleurotomaria reticulata.
f. Patella latissima.
g. Ammonites biplex.

11. The Portland Beds, so called from the promontory known as the Isle of Portland, on the coast of Dorset, have, like most of the other stony groups of the Oolitic series, a variable composition. They consist of sands and sandstones below, becoming in the upper part calcareous, and passing into limestone, which is sometimes oolitic. They are therefore divisible into—

b. Portland Stone, consisting of white oolite and beds locally termed "stonebrash" and "roch" etc., interstratified with clays, and containing layers of chert, about 60 to 90 feet.

a. Portland Sands, consisting of brown or yellow sands and sandstones, sometimes full of green grains; like those afterwards to be described in the Greensands; about 80 feet.



Fossil Group No. 32.

Portland Fossils.

a. Isastræa oblonga.
b. Pecten lamellosus.
c. Cardium dissimile (internal cast).
d. Lucina Portlandica.
e. Trigonia gibbosa.
f. Trigonia incurva (internal cast).
g. Natica elegans.
h. Cerithium Portlandicum.

The beds, especially the lower sands, are to be seen at intervals capping the Oolitic hills as far north as Oxfordshire and Bucks, where

they occur about the summit of Shotover Hill, and in the neighbourhood of Aylesbury. They consist there of sands with marine fossils, over which are "iron sands" with fresh-water forms. Farther north they entirely disappear, for at Ely the Lower Greensand of the Cretaceous series rests directly on the Kimeridge Clay.

The Portland Beds are well developed in the Isle of Purbeck, and also in the Vale of Wardour, in Wiltshire, where they are quarried for building-stone at Chilmack, and in the neighbourhood of Tisbury.

Characteristic Fossils of the Portland Beds.

Actinozoa . .	Isastræa oblonga . . .	Foss. gr. 32, *a*.
Conchifera .	Astarte cuneata . . .	Sow. M. C., 137.
	Cardium dissimile . . .	Foss. gr. 32, *c*.
	Lima obliquata . . .	G. Tr. 2, vol. ii. p. 319.
	Lucina Portlandica . .	Foss. gr. 32, *d*.
	Modiola pallida . . .	Sow. M. C., 8.
	Ostræa expansa . . .	*Ibid.* 238.
	Pecten lamellosus . . .	Foss. gr. 32, *b*.
	Trigonia gibbosa . . .	*Ibid.* 32, *e*.
	——— incurva . . .	*Ibid.* 32, *f*.
Gasteropoda .	Cerithium Portlandicum . .	*Ibid.* 32, *h*.
	Natica elegans . . .	*Ibid.* 32, *g*.
	Neritoma sinuosa . . .	Tab. View.
	Pleurotomaria rugata.	
	Turritella concava . . .	Sow. M. C., 565.
Cephalopoda .	Ammonites giganteus . .	Tab. View.
Echinodermata	Hemicidaris Davidsoni . .	Wright, Foss. E. Pal. Soc.
Fish . . .	Caturus angustus . . .	Ag. Poiss. foss.
	Hybodus strictus . . .	*Ibid.*
	Ischyodus Townshendi . .	*Ibid.*
Reptiles . .	Cetiosaurus longus . .	Ow. Brit. Ass. Rep.

12. **The Purbeck Beds** are so named from their being well developed and clearly exhibited in the district south of the Poole estuary in Dorsetshire, which is known as the Isle of Purbeck. They differ from all the Oolitic series below, in being mostly of fresh-water origin. They are from that circumstance more nearly allied to the Wealden beds above than to the Oolites below, but they contain some marine and other species of fossils, which seem to link them to the Oolites.

Not far above the top of the Portland Stone, on which the shelly limestones of the Purbeck beds repose, there occur one or two "dirt-beds," as they are called by the quarrymen, which are in fact old vegetable soils, including the roots and stems of fossil plants, the remains of an old forest. We have here actual land-surfaces, which having been formed over the marine beds, in consequence, probably, of the gradual elevation of the latter above the sea, were subsequently

buried beneath fresh-water deposits. The latter were formed either in a lake or in the bed of a large tranquil river.

The Purbeck beds have not a greater thickness than 150 or 200 feet. They were examined and described in great detail by Professor Edward Forbes, and subsequently by Mr. Bristow, whose observations will be found in Sheet 56 of the Horizontal Sections and Sheet 22 of the Vertical Sections of the Geological Survey of Great Britain, in the latter of which every bed is drawn on a scale of 1 inch to 10 feet, with full lithological and palæontological descriptions. The former observer divided the Purbeck beds into three groups—Lower, Middle, and Upper—which, without any marked lithological distinctions, nevertheless contain each a peculiar assemblage of fossils. Mr. Bristow's section of Durlstone hill contains the following groups :—

			Feet.	
Upper.		20. Upper Cypris clays and shales	45	69
		19. Unio beds with the Crocodile bed	5	
		18. Upper broken shell limestone (soft burr)	19	
Middle.		17. Chief "beef"* beds	28	130
	Marine Beds.	16. Corbula beds	33	
		15. Scallop beds (white roach)	4	
		14. Leaning vein	6	
		13. Royal (limestone)	5	
		12. Freestone vein	21	
		11. Downs vein	12	
		10. Cinder bed (mass of small *Ostræa distorta*)	8	
		9. Cherty fresh-water beds	8	
		8. Marly fresh-water beds	5	
Lower.		7. Marly fresh-water beds	7	140
		6. Soft cockle beds	60	
		5. Hard cockle beds	9	
		4. Cypress freestone	34	
		3. Broken bands	14	
		2. Soft Cap	6	
		1. Hard Cap, with dirt parting at bottom	10	
				339

At Worbarrow Bay and Mewps Bay, an irregular dirt-bed comes in between the hard and soft Caps, but is not seen at Ridgway Hill according to the Rev. Osmond Fisher. The whole section gradually gets thinner from east to west, till it is not more than 175 feet at the latter place.

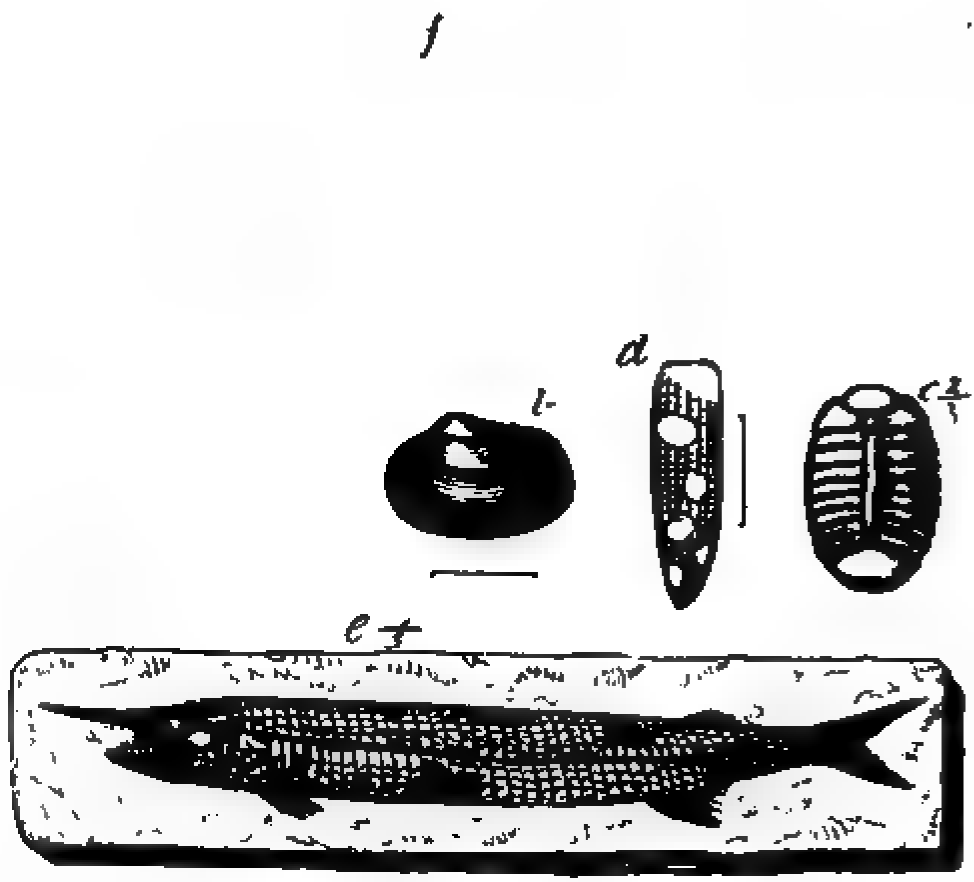
It was in a little band about 20 feet below the cinder-bed, that the very remarkable discoveries of several Mammalian remains were made by Mr. Brodie, and afterwards by Mr. Beckles.†

The Purbeck marble, formerly so much used in the internal decora-

* The Portland quarrymen give the name of "beef" to beds of fibrous carbonate of lime. In the Isle of Purbeck these are called "horse-flesh."

† *Quart. Journ. Geol. Soc.*, vol. xiii. p. 261.

tion of churches and other buildings, was procured from bands of limestone, consisting almost entirely of compacted fresh-water snail shells



Fossil Group No. 33.
Purbeck Fossils.

a. Cycadeoidea microphylla.
b. Cyrena elongata.
c. Archæoniscus Edwardsii.
d. Buprestou stygnus (elytron of).
e. Aspidorhynchus Fisheri.
f. Goniopholis crassidens, tooth.
g. Pleurosternon ovatum.

(*Paludina carinifera*), which was interstratified with the Upper Cypris clays and shales No. 20.*

Characteristic Fossils of the Purbeck Beds.

Plants . . .	Cycadeoidea microphylla .	Foss. gr. 33, *a*.
	——— megaphylla .	Mantell's Meds., fig. 50.
	Dammarites Fittoni . .	G. Tr. 2 ser., vol. iv.
Echinodermata	Hemicidaris Purbeckensis .	Geol. Surv. Decade iii., and Ly. Man. 372.
Crustacea . .	Archæoniscus Edwardsii .	Foss. gr. 33, *c*.
	Cypridea tuberculata . .	Ly. Man., fig. 368, *b*, and Mant. Meds., fig. 174.

* For an account of the Portland and Purbeck formation of these localities, see *Handbook to the Geology of Weymouth and the Island of Portland*, by Robert Damon, F.G.S.

Crustacea . .	Cypridea fasiculata . .	Ly. Man. 371, *b*.
	——— Purbeckensis . .	*Ibid.* 375.
Conchifera .	Cyrena elongata . . .	Foss. gr. 33, *b*.
	Ostræa distorta . . .	Tab. View.
Gasteropoda .	Melanopsis harpæformis.	
	Physa Bristovii . . .	Tab. V., and Ly. Man. 338.
	Paludina carinifera . .	Sow. M. C., 509.
Insects. . .	Æshna perampla . . .	Brod. Foss. In., pl. v.
	Bupreston stygnus . .	Foss. gr. 33, *d*.
	Carabus elongatus . . .	Brod. Foss. In., pl. ii.
Fish . . .	Aspidorhynchus Fisheri . .	Foss. gr. 33, *e*.
	Lepidotus Mantelli . .	Mantell's Meds., fig. 196.
	Microdon radiatus . . .	Ag. Poiss. foss.
	Ophiopsis breviceps . .	M. G. S., Dec. 6.
	Pholidophorus ornatus . .	Ag. Poiss. foss.
Reptiles . .	Goniopholis crassidens (*Crocodilian*)	Foss. gr. 33, *f*, and Mantell's Meds., fig. 207.
	Pleurosternon ovatum (*Chelonian*)	Foss. gr. 33, *g*.
	Macellodus Brodiei (*Lacertilian*)	Q. J. G. S., vol. x.
	Nothetes destructor ,,	*Ibid.*
Mammalia .	Spalacotherium Brodiei . .	*Ibid.*
	Plagiaulax Becklesii . .	*Ibid.* vol. xiii.

Fossils Characteristic of more than one Group.—In selecting groups of species that are peculiarly characteristic of certain groups of beds, certain other species are necessarily omitted which are characteristic of larger parts of the series, being found in almost equal abundance in more than one group.

Of these the following deserve mention :—

Species common to A (Lias), and B (Bath Oolites).

Brachiopoda . Thecidium triangulare ranges from Upper Lias to Cornbrash (*Lycett*).

Species common to A and C (Coralline Oolite).

Conchifera . Modiola cuneata.

Species common to B and C.

Actinozoa .	Thamnastræa concinna.
Echinodermata	Echinus perlatus, Hemicidaris intermedia, Nucleolites orbicularis, N. scutatus, N. sinuatus, Pygaster semisulcatus, Pygurus pentagonalis.
Crustacea . .	Glyphæa rostrata.
Polyzoa . .	Heteropora ramosa.
Brachiopoda .	Rynchonella varians, Terebratula impressa, T. ornithocephala.
Conchifera .	Anatina undata, Gervillia siliqua, Isodonta triangularis, Lima duplicata, Pecten annulatus, P. demissus, Pinna lanceolata, P. mitis, Arca æmula, Cucullæa elongata, C. oblonga, Goniomya literata, G. scripta, Isocardia tenera, Lithodomus inclusus, Lucina crassa, Myacites calceiformis, Quenstedtia lævigata.

Gasteropoda . Alaria trifida, Bulla elongata, Pleurotomaria granulata, Purpurina nodulata.
Cephalopoda . Ammonites macrocephalus.

Species common to B, C, and D (Portland Oolites).

Conchifera . Trigonia costata.

Species common to B and D.

Conchifera . Cardium striatulum, Pecten arcuatus, Pholadomya ovalis.

Species common to C and D.

Brachiopoda . Lingula ovalis.
Conchifera . Astarte ovata, Exogyra nana, Gervillia aviculoides, Lima rustica, Ostræa solitaria, Trigonia clavellata.

SCOTLAND.—Patches of Lias and Oxford Clay, in some of which are estuary beds, occur here and there on the islands of Mull, Skye, Eigg, Raasay, Canna, etc., as well as on parts of the mainland of the western coast of Scotland. Near Brora, on the east coast of Sutherlandshire, rocks similar to the Lower Oolites of Yorkshire are found, containing similar beds of impure coal.*

IRELAND.—The only beds belonging to the Oolitic series in Ireland are some black Liassic shales which are visible in some parts of Antrim. These occur just at the top of the red marls of the Trias, and are probably the basal beds of the Lias. They do not anywhere exceed thirty or forty feet in thickness, but contain often an abundance of characteristic Lias fossils. (See *ante*, p. 615.)†

Foreign Localities.

It has already been said that on the Continent the Oolitic series is called the Jurassic series, because it forms the Jura mountains. The following classification of the beds in that district is the one given by M. Jules Marcou.‡ It is remarkable that although the Jura mountains are at least five times the height of the Cotteswold hills, and occupy more than five times the area of the Oolitic range in England, yet the actual thickness of the beds is, according to Marcou's measurements, considerably less in the Jura than it is in England. In the Jura, however, they are wonderfully bent and contorted into folds of every degree of magnitude, so that beds which, in some parts at least, do not much exceed 1000 feet in thickness, nevertheless make up the principal mass of a large and complicated mountain chain. This chain is composed of no other rocks than the Jurassic and Neocomian beds, and nevertheless far exceeds in height and importance the Palæozoic mountains of England, France, or Germany.§

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* See papers by Sir R. I. Murchison, *Trans. Geol. Soc.*, vol. ii., second series; Edward Forbes, *Quart. Journ. Geol. Soc.*, vol. vii.; Geikie, *op. cit.*, vol. xiv.

† Portlock, *Report on Geology of Londonderry*, etc.; Tate, *Quart. Journ. Geol. Soc.*, vol. xxiii. p. 297.

‡ *Lettres sur les Roches du Jura*, livraison i., in which I have translated the thicknesses from French metres into English feet.

§ For a section showing the folds of the Jura chain, see *ante*, p. 469.

			Feet.
UPPER OOLITE, 493 ft.	XI. Groupe de Salins.	26. Calcaire de Salins . .	106
		25. Marnes de Salins . .	11
	X. Groupe de Porrentruy.	24. Calcaire de Banné . .	132
		23. Marnes de Banné . .	14
	IX. Groupe de Besançon.	22. Calcaire de Besançon .	98
		21. Marnes de Besançon .	16
	VIII. Groupe Corallien.	20. Oolite corallienne . .	24
		19. Coral rag de la Chapelle .	82
OXFORDIAN, 161 ft.	VII. Oxfordien supérieur.	18. Couches d'Argovie . .	98
	VI. Oxfordien inférieur.	17. Marnes Oxfordiennes .	48
		16. Fer de Clucy . . .	16
LOWER OOLITE, 253 ft.	V. Groupe du département de Doubs.	15. Calcaires de Palente. .	20
		14. Calcaires de la Citadelle (Besançon) . . .	65
		13. Calcaires de la porte de Tarragnoz . . .	38
	IV. Groupe du département du Jura.	12. Marnes de Plasne . .	10
		11. Roches de corraux du Fort St. André . . .	33
		10. Calcaires de la Roche pourrie . . .	59
		9. Fer de la Roche pourrie .	33
LIAS, 198 ft.	III. Lias supérieur.	8. Marnes d'Aresche . .	26
		7. Marnes de Pinperdu .	48
		6. Schistes de Boll . .	7
	II. Lias moyen.	5. Marnes de Cernans . .	20
		4. Marnes Souabiennes .	43
	I. Lias inférieur.	3. Marnes de Balingen. .	38
		2. Calcaires de Blégny. .	15
		1. Couches de Schambelen .	5
			1100

Of these groups, M. Marcou identifies his Lias with our Lias generally. He correlates his Oxfordien inférieur with our Oxford Clay, believing his Couches d'Argovie to be unrepresented in England, *unless* by Phillips's gradations between the calcareous grits of the Coral Rag and Oxford Clay in Yorkshire. He also correlates his Marnes de Banné with the Kimeridge Clay, and believes his Groupe de Salins to be the purely marine equivalent of the partly marine and partly fresh-water Purbeck beds. He also identifies the intermediate groups of the Jura with the intermediate groups of the English Oolitic series, with more or less precision. M. Marcou gives a table supporting these identifications by lists of characteristic fossils found in most of his twenty-six subdivisions of the Jurassic series.

*France and Germany.**—Other authors have adopted different designations for different parts of the continental Jurassic series, which it will be best perhaps to give in the following tabular form, referring to the table previously given at p. 623.

D 12. PURBECK BEDS, not identified by d'Orbigny, Marnes de Villars, Serpulit.

D 11. PORTLAND BEDS.—Terrain Portlandien, calcaire à tortues de Soleure. Upper white Jura.

* *Vide* "On the Comparison of the German, French, and English Jura formations," by Oscar Fraas. *Quart. Journ. Geol. Soc.*, vol. vii. pt. 2, p. 42.

D 10. KIMMERIDGE CLAY.—Terrain Kiméridgien, argiles noirs de Honfleur, calcaire à astartes. Part of the Terrain Portlandien of the geologists of the Swiss Jura, who call the lower part Terrain Séquanien; part of Upper white Jura.

C 9. CORAL RAG.—Terrain Corallien, schistes de Nattheim, calcaire à nérinées. Middle white Jura. (The lithographic flags of Solenhofen are believed to belong to this group.)

C 8. OXFORD CLAY.—Terrain Oxfordien, terrain à chailles. Ornaton Thon, Impressa Kalk, Spongiten Lager. Part of brown Jura and Lower white Jura.

C 8 *a*. KELAWAYS ROCK.—Terrain Callovien, Oxfordien inférieur. Part of brown Jura.

B 5. FULLER'S EARTH; 6. GREAT OOLITE; AND, 7. CORNBRASH.—Terrain Bathonien, calcaire de Caen et Ranville. Parkinsoni Bank. Part of brown Jura.

B 4. INFERIOR OOLITE.—Terrain Bajocien, calcaire Lædonien, calcaire à polypiers, marnes Vésuliennes. Eisen-Rogenstein, Discoidien-Mergel. Middle brown Jura.

A 3. UPPER LIAS.—Terrain Toarcien. Posidonomyen-schiefer, Jurensis Mergel, Opalinus Thon. Upper black Jura and lower brown Jura.

A 2. MARLSTONE. — Terrain Liasien. Amaltheen Thon, Numismalen Mergel. Middle black Jura.

A 1. LOWER LIAS.—Terrain Siuémurien, grès du Luxembourg, calcaire de Valognes, grès de Linksfield. Gryphiten-Kalk. Lower black Jura.

The first-mentioned names in the above list are those of D'Orbigny.

In travelling across France and its borders within the limits of the Geological Map of France, by E. De Beaumont and Du Fresnoy, the English geologist cannot fail to be struck with the general resemblance of the Oolitic and Triassic formations to those of his own country. Although it is always unsafe to trust to lithological resemblance, yet it appears certain that there is a wonderful general identity of mineral character in the Mesozoic rocks of Western Europe. When, however, we pass the Jura chain and approach the Alps, the Lias and other Jurassic rocks become completely metamorphosed into clay slates, mica schists, and gneiss, with crystalline limestone (Alpen kalk) like the so-called primary limestones of our old metamorphic districts. The main mass of the Swiss Alps is probably composed of these metamorphosed Oolitic rocks, and it may well be doubted whether any part of the Western Alps shows any but a very few rocks of greater antiquity than the Oolitic Period, although they were at one time supposed to be of primary or "primitive" origin.

America.—Sir C. Lyell describes some of the rocks of North America as like those of the Yorkshire and Sutherland Oolites. They consist of sands and clays, with beds of coal, and contain numerous plants. Professor W. B. Rogers first described the Richmond coalfield of Virginia, which contains many seams of good coal—one thirty or forty feet in thickness—as belonging to the Oolitic Period. It appears, however, from Marcou's *Geology of North America*, that the identification of these beds as of Oolitic age is erroneous, and that they are more probably Triassic (Keuper) than Oolitic. But Marcou describes other marine Oolitic beds as existing in New Mexico, and to the west of the Rocky Mountains, though these are now believed to be Cretaceous. Mr. D. Forbes describes large parts of Peru and Bolivia, on the western side of the Andes, as formed of rocks belonging to the Oolitic Period, consisting of clays, shales, and limestones, with many characteristic Oolitic fossils, but interstratified with great beds of porphyry and porphyry-tuffs and conglomerates.*

India.—Beds containing Ammonites and other fossils, like those of the Lias

* *Quart. Journ. Geol. Soc.*, vol. xvii.

and Lower Oolites, were described by Mr. Grant as occurring in Cutch, and being associated with other beds containing coal and plants of Oolitic genera.* In the 7th vol. of D'Archiac's *History of the Progress of Geology*, these and other beds in the north of India are spoken of as of marine origin and belonging to the Oolitic Period, and a vast central fresh-water formation of Middle and Southern India is also said to belong to the same period. D'Archiac quotes Mr. Carter's "Summary of the Geology of India,"† who says that the Oolitic series of India consists of—

4. Diamond conglomerate.
3. Panna sandstone.
2. Kattra shales, with limestones and coals.
1. Tara sandstone.

1. The Tara sandstone has been called both Old and New Red Sandstone. It is 1000 feet thick and without fossils, but seems to pass up into
2. The Kattra (or Kuttrah) shales, to which, according to Carter, the Burdwan and other coals west of the Hooghly belong, contain plants of the genera *Glossopteris*, *Tæniopteris*, *Vertebraria*, *Zamia*, etc. etc., together with those of other genera, as *Calamites*, *Pecopteris*, *Poacites*, and *Sphenophyllum*, which are both Carboniferous and Oolitic genera.
3. The Panna sandstone has a maximum thickness of 2000 feet, and is capped in some places by
4. The Diamond conglomerate, which contains pebbles of sandstone and quartz, and occasionally diamonds.

These two last groups do not contain fossils, but were believed by Newbold to be of præcretaceous age.

Australia.—In a recent exploration on the western coast Mr. Gregory discovered fossils, such as a Trigonia and Ammonite, which seem more like those of the Oolitic series than any others. This therefore lends some small support to the belief in the Oolitic age of some of the coal-beds of New South Wales, Victoria, and Tasmania, in which plants have been found which were supposed to be necessarily of Oolitic age.‡

Arctic Regions.—St. Anjou, of the Russian navy, asserted many years ago that he had found ammonites in the cliffs of New Siberia, in north latitude 74. Others have since been brought home by Captain Sir Leopold M'Clintock from Point Wilkie in Prince Patrick Island, 76° 20′ north. One of these has been called *Ammonites M'Clintocki*, and compared with *Ammonites concavus* of the Lower Oolites of France by the Rev. Professor Haughton. Sir L. M'Clintock, Captain Sherrard Osborn, and Sir E. Belcher, also found portions of Ichthyosaurus in those regions.§

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* *Trans. Geol. Soc. Lond.*, vol. v. 2d ser.

† *Journ. of Bombay Branch of Asiatic Society.*

‡ In vol. i. p. 8, of Hooker's *Himalayan Journals*, will be found some excellent remarks on the doubtful nature of the evidence as to contemporaneity of beds to be derived from fossil plants, and especially from fossil ferns. He says—"Amongst the many collections of fossil plants that I have examined, there is hardly a specimen belonging to any epoch sufficiently perfect to warrant the assumption that the species to which it belonged can be again recognised. The botanical evidences which geologists too often accept as proofs of specific identity, are such as no botanist would attach any importance to in the investigation of existing plants. The faintest traces assumed to be of vegetable origin are habitually made into genera and species by naturalists ignorant of the structure, affinities, and distribution of living plants."

§ See Appendix to *Fate of Franklin*, by Captain Sir L. M'Clintock. Murray: London, 1859.

CHAPTER XXXVII.

CRETACEOUS PERIOD.

The Cretaceous Period is so called from the Chalk (in Latin, *creta*) which was formed during a part of this time over a large area now occupied by the European quarter of the globe.

We have just seen that the last deposit which took place in the British area during what has been called the Oolitic Period was of fresh-water origin. The first deposits of the Cretaceous Period within that area, according to the grouping adopted by Sir C. Lyell, were in like manner fresh-water deposits. Professor Phillips groups all these fresh-water deposits together, and includes them in the Oolitic series. Perhaps the best way would be to interpolate another distinct period between those called Oolitic and Cretaceous, and to include in it the Purbeck, the Wealden, and the Lower Greensand deposits; but this has not yet been attempted, and it might possibly be attended with as many difficulties as the present classification.

On both petrological and palæontological grounds it is advisable to separate the rocks formed during this period into two large groups, a Lower and an Upper. They may then be tabulated as follows:—

				Feet.
Upper Cretaceous.	8. Maestricht and Faxoe beds, Pisolitic chalk			100
	7. White Chalk, with flints . .		up to	1000 (or more).
	6. White Chalk, without flints .		„	600
	5. Chalk marl		.	100
	4. Upper Greensand . . .		up to	150
	3. Gault		„	200
Lower Cretaceous.	2. Lower Greensand		„	850
	1. Wealden beds	Weald Clay .	600	1500
		Hastings Beds .	900	

The groups 5, 6, and 7, forming together the true Chalk, are the most important and persistent members of the series in Britain. They spread in one unbroken range of high swelling downs across England from Dorchester to the coast of Norfolk, where they are broken through by the broad estuary of the Wash; they re-appear again in Lincolnshire, stretching from the Wash to the Humber, and again in Yorkshire, where they rise into the hills called the Yorkshire Wolds, and terminate in the white cliffs of Flamborough Head. In Wiltshire and Hampshire this ridge is expanded into the wide undulating upland called Salisbury

Plain, from which the chalk spreads towards the east until it separates into two distinct east and west ridges, one called the South Downs running north of Brighton and terminating in Beachy Head; the other called the North Downs, running by Guildford and Rochester to Dover and the North and South Forelands. Another ridge parallel to these starts from Dorchester to Purbeck Hill, and traverses the Isle of Wight from the Needles to Culver Cliffs. Large outlying patches of Chalk occur to the west of Dorchester, the most westerly being near Sidmouth, in Devonshire. It is in the south of England only that the group called No. 1, *The Wealden Beds*, is to be found, chiefly in the country between the two ridges just spoken of as the North and South Downs, or to the southward of that which runs through Purbeck and the Isle of Wight.

The following drawing (Fig. 163) represents a section through part of the west coast of the Isle of Wight, where the Cretaceous series and some of the beds above them may all be seen in the space of about a mile.*

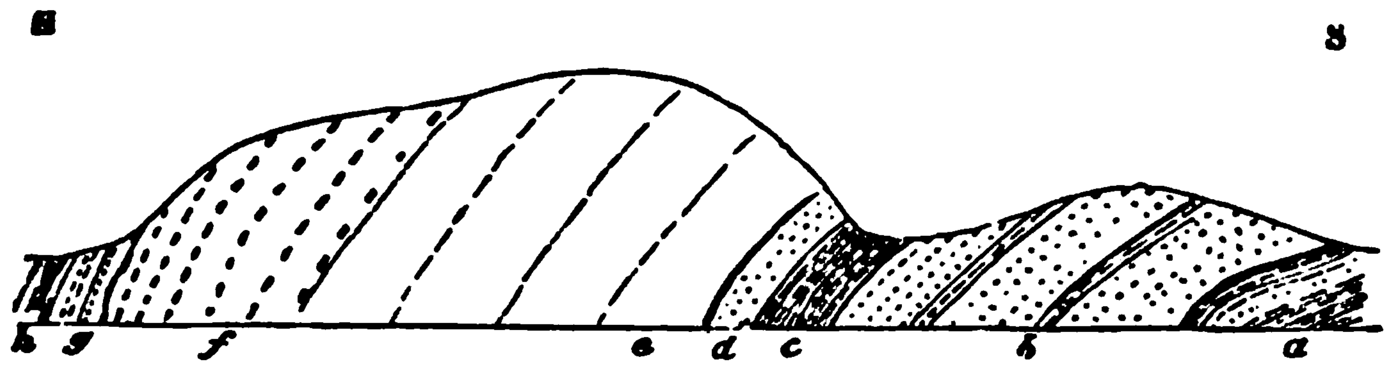


Fig. 163.

Section through Shalcombe Down, on the western coast of the Isle of Wight.

		Feet.
h. London clay	Tertiary rocks.	
g. Plastic clay	Tertiary rocks.	
f. Chalk with flints†		1200 ?
e. Chalk without flints and chalk marl		300 ?
d. Upper Greensand		100
c. Gault		120
b. Lower Greensand		800
a. Wealden beds, exposed to a depth of		400

A similar section by Mr. Bristow is given in Sheet 56, in a line running through Purbeck Hill, in which the total thickness of the chalk is 1400 feet, and that of the Wealden beds also 1400 feet, the Purbeck beds below them showing 196 feet.‡

The Lower Cretaceous Rocks.

Under this division are embraced two groups—the Wealden and the Lower Greensand.

* This section is reduced from Sheet 47 of the Hor. Secs. of the Geol. Survey, drawn by Mr. Bristow.

† The chalk with flints has been made much too thin in this woodcut, and that without flints too thick. See Whitaker, *Quart. Journ. Geol. Soc.*, vol. xxi. pp. 400, 405.

‡ See also the sections on the margin of Professor Ramsay's *Map of England and Wales.*

1. **The Wealden Beds,** so called from their now forming a district known as the Weald of Kent, Surrey, and Sussex, consist of a great series of sandstones, shales, clays, and sands, with a few beds of limestone and ironstone occasionally. They are often full of large fragments of drift wood, and of the remains of fresh-water shells, and of some fresh-water and some land animals (reptiles). In general appearance the Wealden rocks not unfrequently resemble some of the Coal-measures of the true Carboniferous Period. These beds suggest a delta formed at the mouth of some large river, which brought down the sweepings of a great tract of dry land to the area lying between Purbeck and Boulogne.

The Wealden rocks are commonly divided into two groups—

	Feet.
b. The Weald Clay	600
a. The Hastings Sand . . .	1000

Fossil Group No. 24.—Wealden Fossils.

a. Endogenites erosa. *c.* Unio Mantellii. *e.* Cypridea Valdensis.
b. Cyrena media. *d.* Paludina fluviorum. *f.* Iguanodon Mantellii.

These distinctions, however, seem hardly to be carried out by any precise line of demarcation. The lower beds are more arenaceous, and

the upper more argillaceous; but great beds of clay occur interstratified with the Hastings Sands, and beds of sand with the Weald Clay. It is probable that these beds change their character laterally as well as vertically, great banks of sand and large deposits of mud having been formed side by side. The sandstones are sometimes impregnated with carbonate of lime, so as to become calcareous grits, and small beds of limestone (forming Petworth or Sussex Marble), chiefly consisting of fresh-water snail shells (*Paludina*), occur here and there in the clay. Local names were given by Dr. Mantell to the different parts of the Wealden series in different places, as Ashburnham Beds, Worth Sands, Tilgate Beds, Horsham Beds, etc., the Ashburnham Beds being the lowest of the series.

Mr. Drew, late of the Geological Survey, has described* with more precision the greater part of the formation as it exists around Tunbridge Wells, and has since treated of its most easterly extension. His classification, which is adopted on the maps of the Geological Survey, is as follows:—

		Feet.
	5. Weald Clay, with some local beds of stone, 10 feet thick near Horsham, and hence called Horsham stone, lying about 120 feet above the base of the clay	600
HASTINGS BEDS.	4. Tunbridge Wells Sand, with a bed of clay called Grinstead clay, sometimes 50 feet thick, coming in towards the west between the Upper sand above and the Rock-sand below	150 to 200
	3. Wadhurst Clay, with one or two little beds of sand, a shelly limestone, formed of *Cyrena*, and a band of clay-ironstone, once largely used for iron-ore . .	100 to 160
	2. Ashdown Sand, like the Tunbridge Wells sand, and containing subordinate beds of clay and ironstone .	160 to 250
	1. Ashburnham Beds.—Mottled clays, shells, and sandstones, sometimes with layers of limestone; the bottom not shown .	330

Characteristic Fossils of the Wealden Beds.

Plants . . .	Clathraria Lyellii . . .	Mantell's Meds., ch. vi.
	Endogenites erosa . . .	Foss. gr. 34, *a*.
	Equisetum Lyellii . . .	Mantell's Meds., fig. 12.
	Lonchopteris Mantellii . .	Geol. Tr. vol. i., 2d ser.
	Sphenopteris gracilis . .	Ly. Man., fig. 347.
	Thuytes Kurrianus . .	Mantell's Meds., fig. 62.
Conchifera .	Cyrena major . . .	Geol. Tr. vol. iv., 2d ser.
	——— media . . .	Foss. gr. 34, *b*.
	Mytilus Lyellii . . .	Geol. Tr. vol. iv., 2d ser.
	Unio Valdensis . . .	Tab. V. and Ly. Man. fig. 344.
	—— Mantellii . . .	Foss. gr. 34, *c*.
Gasteropoda .	Cerithium carbonarium.	
	Melanopsis tricarinata . .	Geol. Tr. vol. iv., 2d ser.

* *Quart. Journ. Geol. Soc.*, xvii. p. 271. Memoir on Sheet 4 of the Geological Survey Map (1864).

Gasteropoda	Neritina Fittoni	Geol. Tr. vol. iv., 2d ser.
	Paludina fluviorum	Foss. gr. 34, *d*.
	———— Sussexensis	Tab. View.
Crustacea	Cypridea Valdensis	Foss. gr. 34, *e* (magnified).
	Estheria Elliptica, var. subquadrata	Sow. in Fitton's Mem. pl. 17, fig. 8.
Fish	Gyrodus Mantellii	Agassiz.
	Lepidotus Fittoni	Agassiz.
	Pycnodus Mantellii	Agassiz.
	Hybodus subcarinatus	Owen, Pal. p. 105, fig. 26.
Reptiles	Cetiosaurus brevis	Mantell's Til. foss.,* t. 9.
	Chelone Bellii	Mantell's Meds., fig. 240.
	Goniopholis crassidens	Owen, Odont. p. 285, pl. 62, fig. 9.
	† Hylæosaurus Owenii	Mantell's Wond.* 7th ed.
	Iguanodon Mantellii	Mantell's Meds., ch. xvii.
	Pterodactylus Cliftii	*Ibid.* Til. foss.
	Streptospondylus major	Ow. Brit. Ass. Rep.
	Tretosternon Bakevellii	Mantell's Meds., fig. 241.
Birds	Palæornis Cliftii.	

2. The Lower Greensand‡ is best seen at Atherfield and other places in the Isle of Wight, and at Hythe and Folkestone on the coast of Kent. In the latter district it consists of the following beds :—§

	Feet
4. Folkestone Beds, sand with layers of calcareous grit	90
3. Sandgate Beds, greenish clayey sand	80
2. Hythe Beds (Kentish Rag), alternations of sandy limestone, and rather calcareous sand	60
1. Atherfield Clay, brown	30

These divisions vary both in character and thickness westward, and No. 3 is sometimes absent. In Surrey the total thickness is much greater. The clays are sometimes excellent fullers' earth, 60 feet in thickness, and are most abundant in the lower part of the formation, the upper being almost entirely sands. The general colour is dark brown, sometimes red, and the sands are often bound together by an abundance of oxide of iron, from which the formation was formerly called Iron Sand. It has also been called Shanklin Sand from a place in the Isle of Wight. It derives its name of Greensand from the occurrence of a number of little dark green specks (silicate of iron) which are sometimes so abundant as to give a greenish tinge to some of the beds; but the term "green" is generally quite inapplicable as a *description*, though it still remains as a commonly received *name*. The

* Dr. Mantell's *Tilgate Fossils*, and *Wonders of Geology*.

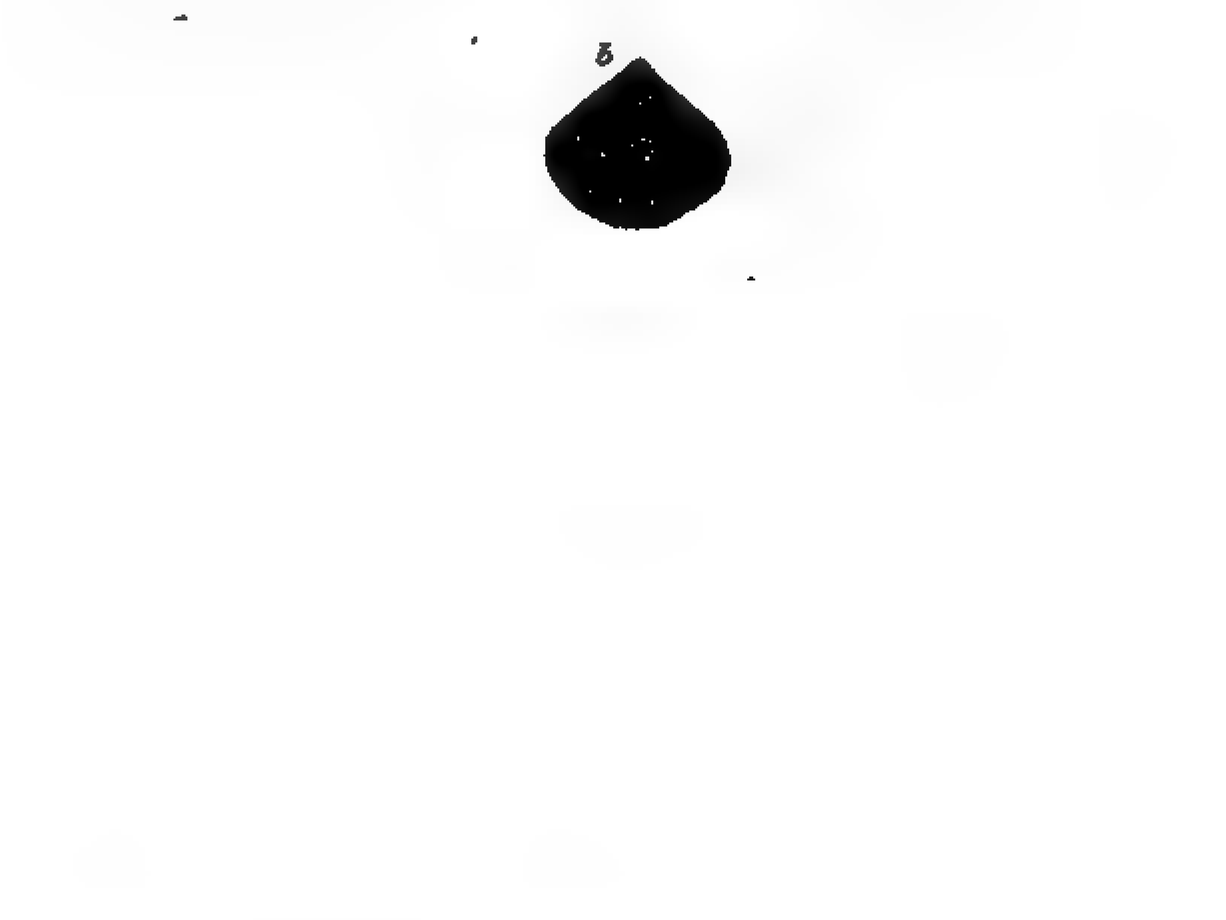
† See also Owen's *Palæontology*, and Buckland's *Bridgewater Treatise*.

‡ For a detailed account of this formation in various parts of England, see Dr. Fitton's paper, *Trans. Geol. Soc.*, ser. 2, vol. iv. p. 103.

§ Memoir on Sheet 4 of the Geological Survey Map (by F. Drew).

whole formation in Britain is very various in character and thickness, its maximum being 843 feet in the Isle of Wight.*

The beds immediately above the Weald Clay show sometimes a sort of passage lithologically, as if partly made up of those below, while the fossils are quite distinct, being entirely marine. It appears that a depression had taken place and allowed the sea to flow over the area which had been previously covered with fresh water. The change may



Fossil Group No. 35.—Lower Greensand Fossils.

a. Holocystis elegans.
b. Rhynchonella Gibbsii.
c. Terebratula sella.
d. Exogyra sinuata.
e. Gervillia anceps.
f. Sphæra corrugata.
g. Ancyloceras gigas.

thus be one of conditions rather than one of great lapse of time—a supposition strengthened by the fact of the bones of the *Iguanodon Mantellii* being found in the Lower Greensand, showing that the great reptile still lived on some neighbouring land, and that an occasional carcass of it was swept out to sea.

At its north-western outcrop (in Oxfordshire, Buckinghamshire, Bedfordshire, and Norfolk), this formation consists of sand, often with

* Forbes and Ibbetson, *Quart. Journ. Geol. Soc.*, vol. i. p. 190; and Fitton, *Ibid.*, vol. iii. p. 289.

masses of iron sandstone. In Berkshire it occurs under the local condition of the "Farringdon Gravel," containing a great number of fossils from oolitic beds, as described by Mr. Godwin Austen.*

Characteristic Fossils of the Lower Greensand.

Plants . .	Abietites Benstedi . . .	Q. J. G. S., vol. ii.
Actinozoa .	Holocystis elegans . .	Foss. gr. 35, *a*.
Echinodermata	Cardiaster Benstedi . .	M. G. S., Dec. 4.
	Hemipneustes Fittoni . .	*Ibid.*
	Salenia punctata . . .	Tab. View.
Crustacea .	Meyeria Vectensis . . .	Mantell's Wonders, fig. 73.
Brachiopoda .	Rhynchonella Gibbsii . .	Foss. gr. 35, *b*.
	Terebratula sella . . .	*Ibid.* 35, *c*.
Conchifera .	Astarte Beaumontii.	
	Cardium sphæroidium . .	Q. J. G. S., vol. i.
	Cucullæa costellata . .	Sow. M. C. 447.
	Cytheræa parva . . .	*Ibid.* 518.
	Exogyra sinuata . . .	Foss. gr. 35, *d*.
	Gervillia anceps . . .	*Ibid.* 35, *e*.
	Myacites mandibula . .	Sow. M. C. 43.
	Perna Mulleti . . .	Tab. V. and Ly. Man., fig. 330.
	Requienia (Diceras) Lonsdaleii	Tab. View.
	Sphæra corrugata . . .	Foss. gr. 35, *f*.
	Thetis minor . . .	Tab. View.
	Trigonia dædalia . . .	Sow. M. C. 88.
	——— caudata . . .	Tab. V. and Phill. Man., fig. 286.
Gasteropoda .	Pleurotomaria gigantea . .	Geol. Tr. vol. iv., 2d ser.
	Pteroceras Fittoni . .	Tab. View.
Cephalopoda .	Ammonites martini . .	*Ibid.*
	Ancyloceras (Scaphites) gigas .	Foss. gr. 35, *g*.
	Belemnites dilatatus . .	Mantell's Med., fig. 141.
	Crioceras Duvalii.	
	Nautilus plicatus . . .	Tab. View.
Reptiles . .	Protemys serrata . . .	Owen. Br. Foss. Rept.

The Upper Cretaceous Rocks.

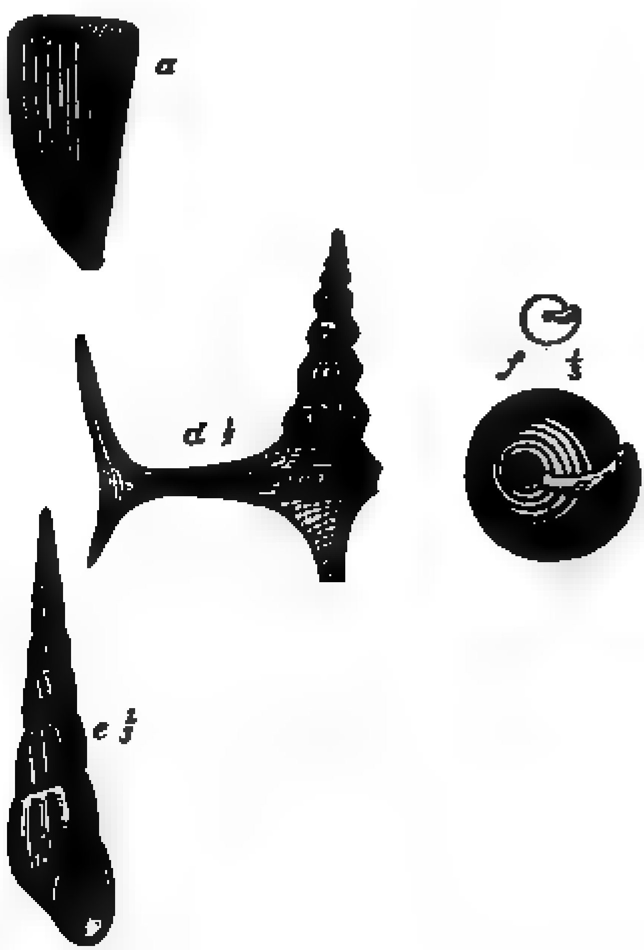
3. Gault.—This is a stiff blue clay, often used for brickmaking. It can be seen very well at Cambridge and at Folkestone, and at various places below the escarpments of the chalk. To the north of Cambridgeshire it stretches into Norfolk, but disappears when the "Red Chalk" sets in. The fossils in it are often beautifully preserved, as in other similar clays, having been well packed and protected from atmospheric or other influences.

Characteristic Fossils of the Gault.

Foraminifera	Rotalina caracolla.	
Actinozoa .	Cyathina Bowerbanki . .	Br. Foss. Cor.
	Cyclocyathus Fittoni . .	Tab. View.
	Trochocyathus conulus . .	Foss. gr. 36, *a*.

* *Quart. Journ. Geol. Soc.*, vol. vi. p. 454.

Actinozoa . .	Trochosmilia sulcata . .	Br. Foss. Cor.
Echinodermata	Hemiaster Bailyi . . .	M. G. S., Dec. 5.
	Pentacrinus Fittoni . .	Geol. Tr. vol. iv.
Annelida .	Serpula articulata . . .	Sow. M. C. 599.
Crustacea .	Notopocorystes Bechei.	
	——— Stokesii . .	Tab. V., and Mant. Med., fig. 168.
Conchifera .	Inoceramus concentricus .	Tab. View.
	——— sulcatus . .	Foss. gr. 36, *b.*
	Nucula pectinata . . .	Tab. View.
	Plicatula pectinoides . .	Foss. gr. 36, *c.*
Gasteropoda .	Dentalium ellipticum . .	Tab. View.
	Natica Gaultina . . .	*Ibid.*
	Rostellaria carinata . .	Foss. gr. 36, *d.*
	Scalaria Gaultina . . .	*Ibid.* 36, *e.*
	Solarium conoideum . .	Tab. View.
Pteropoda .	Bellerophina minuta . .	Foss. gr. 36, *f.*
Cephalopoda .	Ammonites dentatus . .	Tab. View.



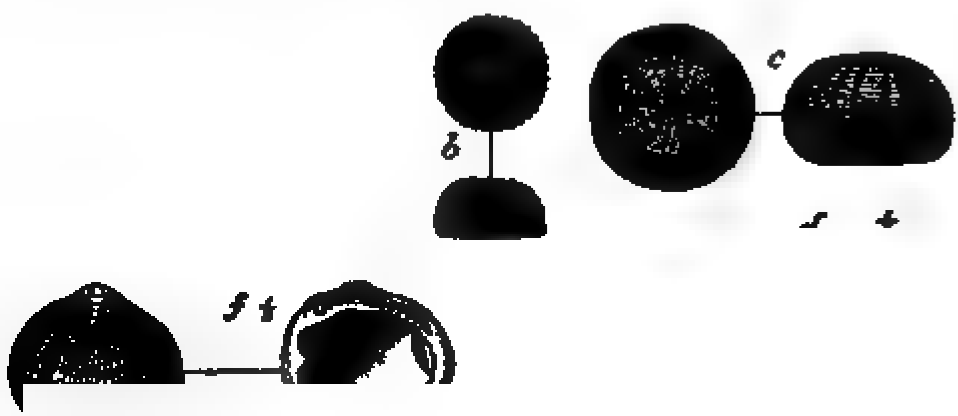
Fossil Group No. 36.

Gault Fossils.

a. Trochocyathus conulus.
b. Inoceramus sulcatus.
c. Plicatula pectinoides.
d. Rostellaria carinata.
e. Scalaria Gaultina.
f. Bellerophina minuta.
g. Ammonites splendens.
h. Hamites attenuatus.

Cephalopoda .	Ammonites lautus . .	Tab. View.
	——— interruptus . .	*Ibid.*
	——— splendens . .	Foss. gr. 36, *g*.
	——— varicosus . .	Tab. View.
	Belemnites minimus . .	*Ibid.*
	Hamites attenuatus . .	Foss. gr. 36, *h*.
	——— (Ancyloceras) spiniger	Ly. Man. fig. 325.
	Heliocceras (Hamites) rotundus	Tab. View.

4. **Upper Greensand.**—This set of beds often resembles the Lower Greensand in lithological character, but the same caution is to be used in taking its designation for a *name* only and not for a *description*, as the sands are by no means always green, and other sands, especially some Tertiary sands, are to be found quite as green, or greener, than



Fossil Group No. 37.—Upper Greensand Fossils.

a. Chenendopora fungiformis.
b. Micrabacia coronula.
c. Echinus granulosus.
d. Terebratula biplicata.
e. Exogyra columba.
f. Pectunculus sublævis.
g. Ammonites auritus.

those which have received the name of "Greensand." In Dorsetshire and the south-west of England the upper part of the deposit is a sandstone or grit, with many bands and layers of chert. This sandstone is the Firestone of Surrey, where it is worked at the foot of the Chalk Downs near Nutfield. In Hampshire the sandstone becomes very cal-

careous and white in colour, so much so as to be easily mistaken for some of the hard beds of the Lower Chalk, into which this Malm Rock (as it is locally called) seems to pass in a northerly direction, so far as mineral character is concerned. A thin bed of phosphatic concretions, sometimes probably coprolitic, and therefore valuable to the agriculturist, is generally met with between the Firestone beds and the lower, most part of the Chalk. This band of Chloritic Marl, as it is called, was assigned to the latter series by Edward Forbes, from the first appearance in it of *Scaphites* and other chalk fossils. It has been surmised that the Upper Greensand may be in part a shore deposit, and therefore contemporaneous with, rather than preceding, the lowest beds of the chalk; but wherever the two are together, we always find the Upper Greensand underneath the Chalk Marl. In Cambridgeshire the Upper Greensand is often not more than nine inches thick, but it thickens towards the west and south, and in Wiltshire and the Isle of Wight is over 100 feet. In the latter place, and in Dorsetshire and Devonshire, it consists largely of sandstone, with layers of chert.

Characteristic Fossils of the Upper Greensand.

Spongidæ . .	Chenendopora fungiformis .	Foss. gr. 37, *a*.
	Siphonia pyriformis . .	Tab. V., and Ly. Man. 320.
	Verticillites anastomosans .	Mant. Med., fig. 70.
Actinozoa . .	Micrabacia coronula . .	Foss. gr. 37, *b*.
	Parastræa stricta . . .	Br. Foss. Cor.
Echinodermata	Catopygus carinatus . .	M. G. S., Dec. 1.
	Diadema Bennettiæ . .	*Ibid.* Dec. 5.
	Discoidea subuculus . .	*Ibid.* Dec. 1.
	Echinus granulosus . .	Foss. gr. 37, *c*.
	Salenia personata . . .	Tab. View.
Annelida . .	Vermicularia concava . .	Tab. View.
Brachiopoda .	Rhynchonella latissima . .	Dav. Cr. Brach.
	Terebratella pectita . .	Tab. View.
	Terebratula biplicata . .	Foss. gr. 37, *d*.
	Terebrirostra lyra . . .	Ly. Man., fig. 323.
Conchifera .	Arca carinata . . .	Sow. M. C., 44.
	Cardium Hillanum . .	Tab. View.
	Cucullæa fibrosa . . .	*Ibid.*
	Exogyra columba . . .	Foss. gr. 37, *e*.
	Gryphæa vesiculosa . .	Sow. M. C., 369.
	Pecten quinquecostatus . .	Tab. View.
	Pectunculus sublævis . .	Foss. gr. 37, *f*.
	Thetis major . . .	Sow. M. S., 513.
	Trigonia dædalia . . .	Tab. View.
Gasteropoda .	Actæon affinis . . .	*Ibid.*
	Natica Gentii . . .	Sow. M. C., 54.
	Turritella granulata . .	Tab. View.
Cephalopoda .	Ammonites auritus . .	Foss. gr. 37, *g*.
	——— rostratus . .	Sow. M. C., 173.
Fish . . .	Edaphodon Sedgwicki . .	Ag. sp. Poiss. Foss. pl. 40, f. 17, 18.

Reptiles . . Professor Sedgwick, at the meeting of the British Association at Oxford, gave an account of the wonderful reptilian remains that had been lately discovered in the little seam of the Upper Greensand at Cambridge, and of their determination by Professor Owen.* Among them were remains of Dinosaurians, analogous to the *Iguanodon*; of *Teleosaurus*; *Ichthyosaurus*, five or six; *Pliosaurus*, one; and ten species of *Pterodactyle*, varying in size from that of a pigeon or Madagascar bat, up to one with a spread of wing 25 feet across. There were also species of Turtles, large and small.

Birds . . . In addition to these, the bones of two species of birds had been discovered, which must have been about the size of a pigeon, but belonged to the order *Natatores*, and were perhaps allied to gulls.

The Chalk.—Over the beds thus described extends the great formation of the true chalk, the subdivisions of which may be thus described:—

5. Chalk Marl.—The top of the Upper Greensand becomes argillaceous, and passes upwards into a pale buff-coloured marl or argillaceous limestone, sometimes of sufficient consistency to be used as a building stone. This in its higher portion begins to lose the argillaceous character, and gradually passes into the soft white pulverulent limestone, familiar to every one as chalk. In Bedfordshire and Buckinghamshire it has, however, a well-marked top bed, known as the "Totternhoe-stone."†

6. White Chalk without Flints.—This is a great mass of soft and often pulverulent limestone, thick-bedded, the stratification often obscure, partly from the obliteration of the bedding planes, partly from the abundance of quadrangular and diagonal joints, the surfaces of which are often weather-stained, dirty green, or yellow. Nodular balls of iron pyrites, radiated internally, are frequent in it, and by their decomposition produce rusty stains in the rock.

7. White Chalk with Flints.—There are no lithological distinctions between the Lower and Upper Chalk, except the occurrence in the latter of rows of nodules of black flint, and occasionally of seams and layers of the same substance. These occur either along the planes of stratification or parallel to them, so that they point out clearly the original bedding of the rock. In Yorkshire and Lincolnshire there are red layers in this division,‡ as is also the case in Northern Germany to a much greater extent.

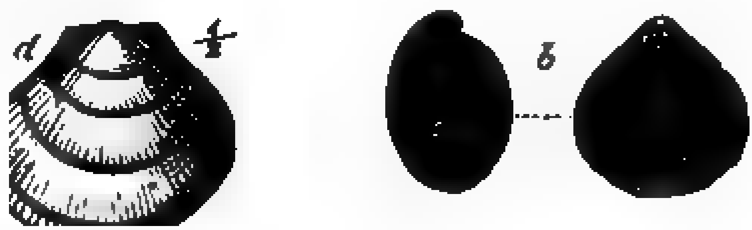
It is rare to find, either in the Upper or Lower Chalk, anything but pure limestone or pure flint. Little pebbles, however, sometimes occur in it, probably carried by the roots of plants; and in a cliff, a little east of Dieppe, I once observed, in the heart of the Upper Chalk, a little band, about 8 inches thick and 20 feet long, of brown clay or marl, perfectly interstratified with the Chalk, and not, as it seemed to

* This seam is probably representative of the chloritic marl of the south-western counties.

† *Quart. Journ. Geol. Soc.*, vol. xxi. p. 398. ‡ *Ibid.*, vol. xxiii. pp. 237-242.

me, connected with any pit-holes, by which it could have been swept in from the surface. Mr. Godwin-Austen has described the occurrence of a large boulder of granite, apparently of Scandinavian origin, which was found in the Chalk near Croydon, and other extraneous fragments both there and elsewhere.*

Although the Chalk and the Carboniferous Limestone are so differ-



Fossil Group No. 36.—Lower Chalk Fossils.

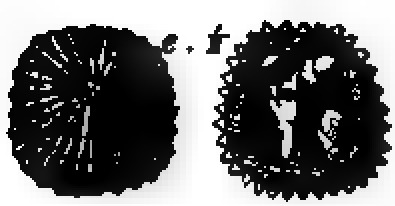
a. Ananchytes subglobosus. *d.* Lima Hoperi. *g.* Scaphites equalis.
b. Rhynchonella Cuvieri. *e.* Ammonites varians. *h.* Turrilites costatus.
c. Inoceramus mytiloides. *f.* Baculites anceps.

ent in texture and induration, there is yet a certain resemblance in the forms of the country they produce. Their hills have equally broad undulating grassy downs, the escarpments of which are quite smooth in the chalk, while they are notched into steps in the Mountain Limestone. Their valleys are alike marked by scaurs, and tors, and pin-

* *Quart. Journ. Geol. Soc.*, vol. xiv. p 252. The best account of the succession of beds in the Chalk, in a limited district, is in the admirable paper by W. Phillips, On the Chalk Cliffs of Dover (*Trans. Geol. Soc.*, ser. 1, vol. v p. 17, 1819; reprinted in Conybeare and Phillips's *Outlines of Geology of England and Wales*). In other parts the component beds seem to be different (Whitaker, *Quart. Journ. Geol. Soc.*, vol. xxi. p. 396).

nacles, as any one may see by comparing the forms of the rocks on the sides of the valley of the Seine with those in the valleys of Derbyshire. The forms are, of course, bolder, larger, and more durable, in the latter than the former.

Characteristic Fossils of the Chalk.—These are very numerous, certain forms being found more or less common throughout the Chalk, and several being common to the whole Upper Cretaceous series, from



Fossil Group No. 30.—Upper Chalk Fossils.

a. Marsupites ornatus. *b.* Goniaster Parkinsoni. *c.* Galerites albogalerus. *d.* Micraster cor-anguinum. *e.* Crania Ignabergensis. *f.* Terebratula carnea. *g.* Inoceramus Lamarckii. *h.* Pecten nitidus. *i.* Belemnitella mucronata.

the Gault to the Upper Chalk. It appears that it is possible to select two lists of fossils, one set being either peculiar to the lower part of the chalk, or most abundant in it; the other set being equally confined to, or most common in, the upper part of it. It seems, however, to me, to be the best for the sake of reference to unite the two lists with which Mr. Baily has supplied me, appending to each species a U. for the Upper Chalk, L. for the Lower Chalk, and M. for the Chalk Marl.

Spongidæ	Choanites Königi, U.	Tab. V. and Mant. Med., fig. 75.
	Ventriculites decurrens, U.	Tab. V.
	——— radiatus, U.	Ly. Man., fig. 318, and Mant. Med., fig. 81.
Foraminifera.	Bulimina obliqua, U.	
	Cristellaria rotulata, U.	Mant. Med., fig. 109.
	Dentalina gracilis, U.	
	Rotalina ornata, U.	
Actinozoa	Cœlosmilia laxa, U.	Brit. Foss. Cor.
	Stephanophyllia Bowerbankii, L.	*Ibid.*
Echinodermata	Ananchytes ovatus, U.	Tab. V. and Mant. Med., fig. 104.
	Ananchytes subglobosus, L.	Foss. gr. 38, *a.*
	Bourgueticrinus ellipticus, U.	Dix. Foss. Suss.*
	Cardiaster granulosus, U.	Tab. View.
	Cidaris perornata, U.	Dix. Foss. Suss.
	Discoidea cylindrica, L.	Mem. G. S., Dec. 1.
	Galerites albogalerus, U.	Foss. gr. 39, *c.*
	Goniaster Parkinsoni, U.	*Ibid.* 39, *b.*
	Marsupites ornatus, U.	*Ibid.* 39, *a.*
	Micraster cor-anguinum, U.	*Ibid.* 39, *d.*
	Salenia Austeni, L.	M. G. S., Dec. 5.
Annelida	Serpula amphisbœna, L.	Goldfuss.
Crustacea	Enoploclytia Sussexiensis, L.	Mant. Med., fig. 169.
Polyzoa	Heteropora cryptopora, U.	
	Lunulites cretaceus, U.	Mant. Med., cut 70, fig. 1.
Brachiopoda	Crania Ignabergensis, U.	Foss. gr. 39, *e.*
	——— Parisiensis, U.	Tab. View.
	Magas pumila, U.	Tab. V. and Ly. Man. 300.
	Rhynchonella Cuvieri, L.	Foss. gr. 38, *b.*
	——— octoplicata, U.	Tab. V. and Ly. Man. 299.
	Terebratula carnea, U.	Foss. gr. 39, *f.*
	Terebratulina striata, U.	Dav. Brach.
Conchifera	Exogyra conica, U.	Sow. M. C. 605.
	Inoceramus Brongniarti, U.	*Ibid.* 441.
	——— Lamarckii, U.	Foss. gr. 39, *g.*
	——— mytiloides, L.	*Ibid.* 38, *c.*
	Lima Hoperi, L.	*Ibid.* 38, *d.*
	Ostræa frons, L.	Sow. M. C. 365.
	——— vesicularis, U.	Ly. Man. fig. 309.
	Pecten Beaveri, L.	*Ibid.* fig. 304.
	——— nitidus, U.	Foss. gr. 39, *h.*
	Plicatula inflata, L.	Sow. M. C. 409.
	Pholadomya decussata, L.	Phill. G. Y. t. 2.
	Spondylus (Plagiostoma) spinosus, U.	Tab. View.
Gasteropoda	Avellana cassis, L.	D'Orbigny.
	Phorus canaliculatus, L.	*Ibid.*
	Pleurotomaria perspectiva, U.	Sow. M. C. 428.
Cephalopoda	Ammonites complanatus, L.	*Ibid.* 94.
	——— Rothomagensis, M.	Ly. Man., fig. 324.
	——— varians (Chloritic marl), L.	Foss. gr. 38, *e.*
	Baculites anceps, L.	*Ibid.* 38, *f.*
	Belemnitella mucronata, U.	*Ibid.* 39, *i.*

* Dixon's *Fossils of Sussex.*

Cephalopoda .	Belemnitella plena, L. . .	Sharpe, Chalk Moll.*
	Hamites simplex, L. . .	D'Orbigny.
	Nautilus elegans, L. . .	Mant. Med., fig. 151.
	Scaphites equalis, L. . .	Foss. gr. 38, *g*.
	Turrilites costatus, L. . .	*Ibid.* 38, *h*.
Fish . . .	Beryx Lewesiensis, U. . .	Mantell's Wond., fig. 83.
	Lamna acuminata, U. . .	Dix. Foss. Suss.
	Macropoma Mantellii, U. .	Mantell's Wond., fig. 80.
	Osmeroides Lewesiensis, U. .	*Ibid.* 79.
	Otodus appendiculatus, U. .	Dix. Foss. Suss.
	Ptychodus decurrens, L. .	Ly. Man., fig. 321.
Reptiles . .	Chelone Benstedi, L. . .	Mant. Med., fig. 238.
	Dolichosaurus longicollus, L. .	Dix. Foss. Suss.
	Ichthyosaurus campylodon, L.	*Ibid.*
	Mosasaurus gracilis, U. .	Mant. Med., ch. xvii.
	Plesiosaurus Bernardi, L. .	Dix. Foss. Suss.
	Polyptychodon interruptus, L.	*Ibid.*
	Pterodactylus Cuvieri, L. .	Ow. Br. Foss. Rep.

There are in Britain † no beds containing chalk fossils, or in any way belonging to the Chalk, lying above the true Chalk with flints.

8. Maestricht or Pisolitic Chalk.—In parts of the North of France, however, there occur curious banks of a white pisolitic limestone, resting apparently in hollows of the chalk, not always on exactly the upper portion of it, and being therefore apparently slightly uncomformable to it. It occurs also sometimes on the same level as the lower beds of the Tertiary rocks about it. The fossils are rather peculiar, but some of them are true Cretaceous, while none I believe are Tertiary forms. Near Maestricht, in Holland also, the chalk with flints (No. 7) is covered by a kind of chalky rock with grey flints, over which are some loose yellowish limestones, without flints, and being sometimes almost made up of fossils. Similar beds, containing some of the same fossils, occur also at Faxoe in Denmark.

Characteristic Fossils.—Together with several true Cretaceous fossils, such as *Pecten quadricostatus*, *Belemnites mucronatus*, *Terebratula carnea*, etc., these beds contain species of the genera *Voluta*, *Fasciolaria*, *Cypræa*, *Oliva*, *Mitra*, *Cerithium*, *Fusus*, *Trochus*, *Patella*, *Emarginula*, etc., several of which genera are elsewhere found in Tertiary rocks only. In the beds near Maestricht, the head of a large lacertilian reptile was formerly discovered, which received the name of *Mosasaurus Hofmanni*,‡ of which the head alone is more than three feet long.§

Outlying English Deposits.—There are some outlying deposits in different parts of England, respecting which there are some doubts as to their exact place in the series.

* "Chalk Mollusca," by D. Sharpe—*Pal. Soc.*

† It was stated at the meeting of the British Association at Oxford that near Norwich beds occurred like the Maestricht chalk. It was also said that a boring had been put down there 800 feet in the chalk with flints, without piercing through into the Chalk without flints.

‡ Mantell's *Meds.*, Fig. 227. § Owen's *Palæontology*, p. 279.

The **Speeton Clay** of Yorkshire lies immediately underneath, but unconformable to, the "Red Chalk," and rests upon the Coralline Oolite. In its lower part it consists of beds of Kimeridge and Portland age, but in its upper part we find 500 feet of blue clay, which by its characteristic fossils is proved to belong to the "Neocomian" formation, the higher part being the equivalent of the Lower Greensand of the south of England, and the lower part probably representing the Wealden.* Like beds, but interbedded with sandy limestones, sandstones, and ironstones of oolitic structure (the "Tealby Series"), occur in Lincolnshire.† The whole of these beds have a remarkable resemblance to the Neocomian (Hilsthon and Hilsconglomerat) of North-western Germany, and they are especially interesting, as being the only representatives of the lower part of the marine Neocomian in this country.

The Greensands of Black Down, on the borders of Devonshire, include a mixture of fossils which elsewhere are confined to the Lower Greensand, the Gault, and the Upper Greensand.

The fresh-water iron sands capping Shotover Hill, near Oxford, have been mapped as Lower Greensand by the Geological Survey, though it is possible that these may belong to the Wealden beds.‡

The Red Chalk at the base of the White Chalk of Norfolk, Lincoln, and Yorkshire, in which latter locality it rests unconformably on the Speeton clay, is peculiar, not only from its lithological character, but from containing some peculiar fossils, along with others, that range from the Gault into the Chalk. Mr. H. Seeley § supports the supposition of its being a part of the Upper Greensand, which is not otherwise represented north of Cambridge; but the Rev. T. Wiltshire classes it with Gault.||

The existence of local groups of rock, however, that will not exactly fit into the general series, either from their containing fossils different from those found in any other group, or from their uniting parts of two sets of fossils which are elsewhere distinct—although sometimes perplexing—seems to me neither unnatural nor different from what might be expected. It merely shows us that which has been often before insisted on, namely, that our series is a series of fragments, and not one of absolutely continuous succession. The intervals of time which have elapsed between the deposition of successive beds have been often very great, those between formations may have been still vaster; hence the local deposits formed here and there during these intervals will of course often have characteristics different from, or intermediate between, the preceding and following groups.

* J. W. Judd, *Quart. Journ. Geol. Soc.*, vol. xxiv. p. 218. † *Ibid.* vol. xxiii. p. 227.

‡ See *Geol. Survey Memoirs*, Sheet 13; and also Prof. Phillips in *Quart. Journ. Geol. Soc.*, vol. xiv. p. 236.

§ In a paper in the *Annals and Magazine of Natural History*, for April 1861.

|| *Quart. Journ. Geol. Soc.*, vol. xxv. p. 185.

Lie and Position of the Cretaceous Rocks in England.— There is yet another cause for uncertainty in the exact determination of the date of some of the deposits at the base of the Cretaceous series in different parts of England, and that is, that they are always more or less unconformable to the Oolitic rocks below. A surface of erosion was formed upon the Oolitic rocks before the deposition of the Cretaceous beds, thus producing irregularities in the nature and thickness of the latter, as well as gaps in the series. According to Professor Phillips, erosion is apparent in Oxfordshire in the Oolitic series itself, since he attributes the absence of the upper part of the Coralline Oolite there to its erosion, before the deposition of the Kimeridge Clay, and it has long been known that from Oxfordshire towards the north-east, the Oolitic beds, from the Oxford Clay upwards, are successively overlapped by the Lower Cretaceous beds. The occurrence of a little bank of Coral Rag near Upware, between Cambridge and Ely, makes the former continuity of that formation probable.

When we get into Yorkshire, we know that the Chalk itself rests on the Lias, owing apparently to a local elevation of the Oolitic beds above the sea, and their consequent denudation before the deposition of any of the Cretaceous series, as shown in Phillips's section to his paper on the Oolites of Yorkshire.*

The proof of elevation and denudation having taken place in the Oolites before the deposition of the Cretaceous series, is interesting when taken in connection with the fact that at Harwich, Kentish Town, and Calais, deep borings put down in search of water have, after passing through the Cretaceous series, come down, not into Oolitic rocks, but into others apparently of Palæozoic age. At Harwich they found a dark grey slate with *Posidonomya*, at a depth of about 1025 feet, just below the base of the Gault. At Kentish Town they reached the base of the Gault at 1113 feet, and then passed through 188 feet of red rocks, clays, sandstone, and conglomerates, some of which appeared to me very like the trappean breccia of the Permian rocks of the Midland Counties.† At Calais the Chalk was pierced, and rocks identified as true Coal-measures were reached at the depth of 1100 feet. On following the nearly horizontal Chalk into the north of France and Belgium, the Carboniferous and other Palæozoic rocks in a highly contorted state come out from underneath it, having suffered vastly from the denudation which produced the surface on which the Cretaceous rocks were deposited.

Drawing a conclusion from these facts, Mr. Godwin-Austen, before the boring of the wells at London and Harwich, suggested the probability

* *Quart. Journ. Geol. Soc.*, vol. xiv.

† See Prestwich, *Quart. Journ. Geol. Soc.*, xii. and xiv.; and Memoirs of Geological Survey, Sheet 7.

of a ridge of Carboniferous and other Palæozoic rocks existing at no great depth, and reaching from the Ardennes and the Eifel on the east, to the neighbourhood of Bristol, Somerset, and Devon on the west, this old ridge being overlaid unconformably by the Mesozoic rocks—the Triassic, the Oolitic, and the Cretaceous deposits successively overlapping each other from west to east, as the old Palæozoic land became successively submerged in that direction.*

It is not improbable that the anticlinal of the Weald and Salisbury Plain, and the synclinal of the Hampshire basin, with its sharp uniclinal curve running through the Isles of Wight and Purbeck, may be referable to some features in the old surface below, producing an effect upon the newer rocks above them, when they were all subsequently acted on by disturbing forces, re-directed perhaps into the old east and west lines along which they had acted at the close of the Palæozoic period.

IRELAND.—In the County Antrim and its borders, Chalk with flints occurs with a maximum thickness of about 200 feet. It lies horizontally near the top of the hills, just west of Belfast, and spreads in horizontal sheets over the whole county, but is generally covered by an immense capping of basaltic rocks, so as only to show itself round the edge of the basalt, or as outliers on the top of some of the adjacent hills. (See Fig. 165.) It is called in Ireland White Limestone, as the stone is considerably harder and firmer than the friable rock which is commonly known as Chalk. It contains an abundance of fossils of the same species as those found in the Chalk of England, but also others in addition, especially a number of univalve shells.† Mr. Sharpe, in the publications of the Palæontographical Society, describes four species of Ammonites as peculiar to the north of Ireland, and one as common to it and the north of France. He believes it to be contemporaneous with the Upper Chalk. It rests, however, conformably on, and seems to pass down into, a pale sandy stone, mottled with green specks, which becomes a loose, dark, green sand below, and is known in the country by the name of Mulatto stone. This is never more than about 20 feet thick. It is full of *Exogyra* and other fossils of the Upper Greensand, so that if the White Limestone above it be the Upper Chalk, the Lower Chalk must be absent. The Greensand rests directly on 30 feet of black shales with Lias fossils, and that on the Red Marls of the Trias.‡ (See section, Fig. 165.)

Foreign Localities.

Switzerland.—The Cretaceous series as now described spreads over a large part of western Europe. The Wealden beds may be seen at Boulogne, with much the same characters as they have in the Isle of Wight, but much thinner.§ As, how-

* Godwin-Austen on Possible Extension of Coal-measures beneath south-east of England. *Quart. Journ. Geol. Soc.*, vol. xii.

† See Jukes' *Geol. Mag.*, v. p. 345.

‡ See Tate, *Quart. Journ. Geol. Soc.*, vol. xxi. p. 15 (1865).

§ See Topley, *Quart. Journ. Geol. Soc.*, vol. xxiv. p. 472.

ever, they are of fresh-water origin, we should expect to meet somewhere with their contemporaneous marine deposits. M. Thurman formerly described beds in the neighbourhood of Neufchatel in Switzerland, which are probably the marine equivalents of the Wealden beds. They have since been called Neocomian, from the Latinised name of the Swiss town.

M. Marcou * gives the following tabular account of these beds, and of what he believes to be their English equivalents :—

	Switzerland.	*England.*
UPPER NEOCOMIAN.	6. White limestones. 5. Limestones with green grains.	Lower Greensand (the bottom part of it).
MIDDLE NEOCOMIAN.	4. Marls of Hauterive. 3. Yellow Limestone.	Weald Clay and Hastings Sand.
LOWER NEOCOMIAN.	2. Limonite. 1. Blue marls unfossiliferous.	

It appears that the blue unfossiliferous marls, No. 1, are now known to contain a few small fresh-water and terrestrial species.

The following Table gives some of the other Continental terms for the different parts of the British series :—

BRITISH.	D'ORBIGNY.	Feet.	OTHER AUTHORS.
Wanting . . .	Danien . .	50	Craie pisolitique. Maestricht and Faxoe beds.
Chalk with and without flints	Sénonien . .	980	Craie blanche, Kreide, Scaglia, Obere and Untere Kreide, and Plæner Kalk, Zone de Rudistes, Calcaire à Hippurites.
Chalk Marl .	Turonien . .	650	Craie tufau, ou chloritée.
Upper Greensand	Cenomanien	1600	Glauconie crayeuse, Quadersandstein, Tourtia, Oberer Karpathensandstein, Système nervien.
Gault . . .	Albien . .	150	Système Aachénien, argiles tégulines (in part).
Speeton Clay .	Aptien . .	650	Argile à plicatules, Argiles tégulines (in part).
Lower Greensand and Wealden Beds	Neocomien	8000	Calcaire à spatangues, Argile ostréene, Calcaire à Dicérates, Hilsconglomerat and Hilsthon, Marne de Hauterive, Terrain Jura-Cretacée, Biancone.

* *Lettres sur les Roches de Jura.*

M. Alcide D'Orbigny says that the Neocomien beds between Marseilles and Cassis, and between Clujes and Beausset, dip at 23° for a distance of 8 kilometres, or nearly five miles, which gives, he says, a thickness of 2500 metres (8200 Eng. feet). The thickness of his Aptien beds he gets at Bedoule in the Basses Alpes; and those of his Cenomanien and Turonien he takes from the measurements of M. Ed. de Verneuil (a most trustworthy authority) made in the provinces of Biscay and Santander in Spain.*

North America.—Sir C. Lyell describes in his Manual sandy and argillaceous beds as existing in New Jersey, and containing fossils of the same species as those of the Chalk of Europe. They extend through North Carolina and Georgia round the southern termination of the Appalachian chain into Alabama and Mississippi.

Dr. Hector describes a great series of sandstones, clays, and shales as occupying all the central part of British North America east of the Rocky Mountains.† These beds are full of fossils belonging to the genera *Exogyra*, *Inoceramus*, *Baculites*, *Scaphites*, and other Cretaceous forms. They likewise contain fossil plants and wood, and beds of good coal, some of which are six feet thick, and are said by Dr. Percy, who examined specimens in his laboratory, to look very like coal from the Coal-measures.‡ Messrs. Meek and Hayden have described the extension of these beds southwards into the American States.

South America.—Mr. Darwin describes in the Andes of the neighbourhood of Coquimbo, great beds of brown argillaceous limestone, porphyritic conglomerates, and masses of red sandstone with gypseous rocks, not less than 6000 feet thick, as containing in some parts fossils such as *Hippurites* and *Baculites*, and others clearly Cretaceous, together with *Spiriferæ* like *Sp. Walcottii*, and other fossils more like Oolitic than Cretaceous species.§ He says in his summary‖ that strata characterised by Cretaceous or Oolitico-cretaceous fossils, having in many places a thickness of 7000 or 8000 feet, may be traced from Columbia north of the Equator to Tierra del Fuego. They consist of "black calcareous shaly rocks, of red and white siliceous sandstones, coarse conglomerates, limestones, tuffs, dark mudstones, and those singular fine-grained rocks which I have called pseudo-honestones, vast beds of gypsum, and many other jaspery and scarcely describable varieties, which vary and replace each other in short horizontal distances to an extent I believe unequalled even in any tertiary basin." "In Tierra del Fuego, at about this same period, a wide district of clay slate was deposited,¶ which, in its mineralogical characters and external features, might be compared to the Silurian regions of North Wales." **

India.—Deposits at Pondicherry, Verdachellum, and Trichinopoly, examined by C. J. Kaye and the Rev. W. H. Egerton, were shown by Professor E. Forbes's examination of the fossils to belong to the Cretaceous Period, the Pondicherry beds to the lower part of it, and those of Trichinopoly and Verdachellum probably to the Gault and Upper Greensand. ††

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* *Cours Elementaire de Palæontologie*, A. D'Orbigny, tom. 2me.

† *Quart. Journ. Geol. Soc.*, vol. xvii.

‡ Percy's *Metallurgy*, p. 89.

§ *South America*, Darwin, p. 212, etc.

‖ *Ibid.* p. 238.

¶ Mr. Darwin, of course, means that clay was deposited, which was afterwards metamorphosed into slate.

** *South America*, Darwin, p. 239.

†† *Quart. Journ. Geol. Soc.*, vol. i. p. 79.

CHAPTER XXXVIII.

III. THE TERTIARY OR CAINOZOIC PERIODS.

EOCENE PERIOD.

THE nomenclature of the Tertiary periods proposed by Sir C. Lyell, and now all but universally adopted, is more systematic than that of the Primary or Secondary periods. It is based on the gradual increase of existing species in the newer rocks. The earliest of the periods is termed Eocene, from the Greek words ἠώς and καινος, signifying the dawn of the recent; the second, Miocene, from μειον, the minority of recent species; the third, Pliocene, from πλειον, the plurality of recent species; and the next, Pleistocene, which expresses the recentness of most of the species. In speaking of these species, however, it must be borne in mind that we refer solely to the shells of the mollusca, as our best standard of comparison for the whole series of the geological formations. Sir C. Lyell takes 5 per cent as the maximum of existing species in any Eocene rock, while in some beds there may be none at all; 18 to 25 per cent as about the range for the Miocene period, upwards of 50 per cent for the Pliocene, while, when the recent shells amount to 95 per cent, we may consider the deposits as Pleistocene.

Moreover, we must recollect that the existing species may no longer live in the same region in which they are found fossil. Mr. Godwin-Austen observes that none of the European Eocene species now exist in any European sea, the present European molluscous fauna not having come into existence till near the end of the Miocene period.*

The adoption of this principle of classification was rendered more necessary in the case of the Tertiary than the preceding epochs, from the nature of the physical conditions of Western Europe, on the structure of which our classification is chiefly based. In the Primary and Secondary epochs, the area now occupied by Western Europe seems to have generally contained more sea than land, and the rocks deposited are accordingly so widely spread as frequently to rest one upon the other. We can therefore often determine their order of superposition

* Godwin-Austen, in Forbes' *Nat. Hist. Europen Seas*, p. 251.

by their geognostic relations only—that is, by actually tracing each group of beds till we find it plunging under the superior group on the one side, or till the inferior group rises up to the surface from underneath it on the other. When, however, we come to examine the Tertiary rocks of the same area, we find that, either from having been deposited in separate seas, or from subsequent denudation, or from both causes combined, they now form detached patches, each patch ending before it comes in contact with the rest, so that their order of superposition can rarely be determined by simple inspection. To take a conspicuous instance at once—the Chalk of the south-east of England is continuous with that of France* and Belgium, and no mistake could possibly be made as to the relative position of the beds above and below it. The Oolites below the Chalk are even still more extensive, and can be traced both geognostically and palæontologically. The Tertiary beds above the Chalk, however, form isolated districts in the synclinal hollows of the Chalk, one being called the Hampshire basin, another the London basin, and a third the Paris basin ; and if we wish to determine whether the beds of these three districts are of the same age, or one older than another, it is obvious that we can no longer employ the positive evidence of an inspection of their superposition. We must then have recourse either to the petrological evidence of their being made exactly of the same kinds of rock occurring in the same order, or to the palæontological evidence of their containing the same assemblages of fossils occurring in the same order ; but if neither rocks nor fossils were precisely the same, then we must fall back on the general rule or principle just spoken of, and see which contained an assemblage of fossils having the greatest approximation to living forms, and this in the case of Tertiary rocks is most easily determined by the relative percentage of actually existing species.

In the description of the range of the Chalk across England, it was pointed out that a nearly continuous escarpment extended from the Wolds of Yorkshire into Dorsetshire, and that the dip of the beds was from the escarpment towards the east, at a gentle angle. It follows that, as the top of the Chalk declines towards the east, and sinks beneath the level of the ground, it must become covered by some other formations.

In Yorkshire, Lincolnshire, and Norfolk, the escarpment of the Chalk runs almost parallel to the sea-coast ; and in consequence of that, and its gentle dip, the formation has no room to acquire any depth before reaching the sea. From Suffolk, however, it strikes directly south-west, through the heart of the country to Dorset, while its general dip is towards the south-east. It becomes covered

* That the shallow furrow of the Straits of Dover has been worn down a little way below the level of the sea into the body of the Chalk does not of course affect this assertion.

towards the south-east, therefore, by a very considerable thickness of beds of more recent formation, most of which belong to the Eocene Period.

There can be little doubt that some of the lowest of these Eocene beds, if not the whole of them, once stretched horizontally across the whole south-east corner of England, from the coast of Suffolk to that of Dorsetshire. Since that time, however, the rocks below have been abruptly elevated along the two east and west lines, or axes, mentioned before, the one running from Salisbury Plain through the Weald of Kent, and the other along the south coast of Dorset and the southern part of the Isle of Wight.

The denudation consequent on the lifting of the rocks along these two bands has removed not only the Eocene beds, but in some parts the whole of the upper and a good part of the lower Cretaceous series. Where, however, the elevation was not so great, the Cretaceous rocks have been spared, as for instance on Salisbury Plain and the Chalk between it and the Weald; and here some very small outlying patches of the Eocene beds have also been left unremoved on the top of the Chalk.* It is then, in consequence of this subsequent elevation and denudation that the Tertiary beds, which repose in a synclinal hollow of the Chalk around London, are separated from those lying in the like hollow of the Chalk around Southampton.

The Chalk beds of the North Downs, running from Deal and Dover to Guildford and Basingstoke, dip to the north and plunge under the valley of the Thames to a depth of many hundred feet, from which they rise very slowly and gradually out towards the north-west. Any one travelling, even by railway, from London southwards to Reigate, on the one hand, or in a north-westerly direction, to Tring, upon the other, will see the difference between the bolder rise of the Chalk from beneath the London basin on the south, and its slower and more gradual elevation on the north. In Kent, however, the rise is gradual. In the Hampshire basin the same features are still more marked, since the Chalk, with the superincumbent Eocene beds, dips very gently southwards from Salisbury and Winchester to the Isle of Wight, where they are suddenly bent up into a position of absolute verticality, as is also the case in Dorsetshire.

The Eocene beds of England rest upon the upper surface of the Chalk in apparent conformability; that is, there is no apparent difference in the dip or strike of the two groups.† That there is, however, an unconformability between them, seems probable.

Owing to the character of the ground, there is no one place where a good continuous section of the whole of the Eocene beds is to be seen

* See Map, Sheets 11 and 12 of the Geological Survey.

† See Prestwich, *Quart. Journ. Geol. Soc.* viii. 256.

in the London basin, and, moreover, they are not all present in that basin. In the Hampshire basin, however, especially on the southern side of it, in the Isle of Wight, where the beds are tilted up along with the Chalk, and exposed in the sea cliffs, excellent continuous sections are to be seen ; also in Alum Bay, at the western extremity of the island, and at Studland Bay in Dorsetshire. The following figure, 164, is a diagrammatic section of the beds as they are shown along the western shore of the Isle of Wight.*

In this section we have, within the space of half-a-mile, the whole of the British Eocene series, with the exception of the uppermost mem-

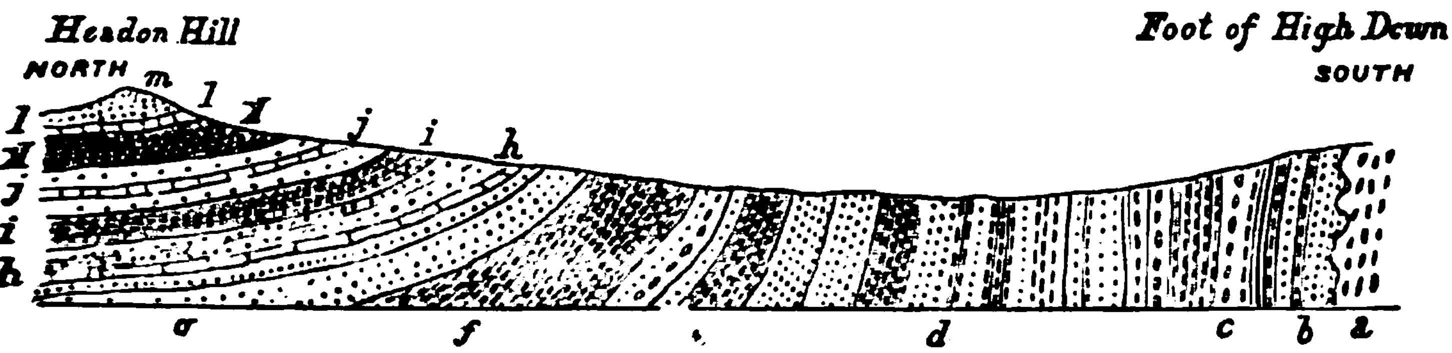


Fig. 164.

Length of section about 700 yards.

m. The High level Gravel.
l. Bembridge Beds.
k. Osborne Beds.
j. Upper Headon Beds.
i. Middle Headon Beds.
h. Lower Headon Beds.
g. Upper Bagshot Beds.
f. Barton Clay.
e. Bracklesham Beds.
d. Lower Bagshot Sands and Clays.
c. The London Clay.
b. The Woolwich and Reading Beds (plastic clay and sands).†
a. The Chalk, having many layers of flint.

NOTE.—In this figure the wood-engraver has unfortunately not copied the original drawing quite accurately, but has made the lines of the group *f* end against the base of the group *g*, as if the Upper Bagshot beds rested unconformably on the Barton clay. The lines of *f* should have been drawn parallel to its boundaries on each side.

ber, namely the Hempstead beds, which are found in a hill four or five miles north-east of Headon Hill. Including these, and tabulating the whole series, as it may be seen in both the London and Hampshire basins, we get the following list of consecutive groups.‡

* Reduced from the one drawn by Mr. Bristow, and published in the *Memoirs Geol. Surv.* (*Tert. Fluv. Mar. formation of I. of Wight*). See also Sheet 47 Hor. Sect., and Sheet 25 Vert. Sect., by same author.

† Formerly called Plastic Clay, on account of the beds of that clay found in this subdivision.

‡ The thicknesses are taken, so far as regards the Upper and Middle Eocenes, from the *Survey Memoir* by Professor Forbes and Mr. Bristow, entitled *Tertiary fluvio-marine Formation of Isle of Wight*; those of the Lower Eocene are chiefly from Mr. Prestwich's papers on different parts of the London basin. They are either the maximum thickness anywhere observed, or the mean of the maxima at different places. See also the general Memoir on the Geology of the Isle of Wight, explanatory of Sheet 10 of the Geological Survey, by H. W. Bristow.

				Feet.	
Upper Eocene.	7. Hempstead Series.	d. Corbula beds	15	170	
		c. Upper freshwater and estuary marls	40		
		b. Middle	50		
		a. Lower	65		
	6. Bembridge Series.	d. Upper marls c. Lower marls b. Oyster bed	90	115	
		a. Limestone	25		
Middle or Paris Eocenes.	5. Osborne Series.	b. St. Helen's Sands	50	70	
		a. Nettlestone Grits	20		
	4. Headon Series.*	c. "Upper freshwater"	85	200	
		b. Middle marine	50		
		a. "Lower freshwater"	65		
	3. Bagshot Series.	d. Upper Bagshot	200	1270	
		c. Middle Bagshot — Barton clay	300		
		b. Middle Bagshot — Bracklesham Beds	110		
		a. Lower Bagshot (in Isle of Wight)	660		
					1825
Lower Eocenes.	2. London Clay.	In London Basin			480
	1. Lower London Tertiaries.†	c. Oldhaven Beds.†			
		b. Woolwich and Reading Beds, in London Basin 90 feet, in Isle of Wight			160
		a. Thanet Beds (in London Basin only)			90
					2555

The Lower Eocene Groups.

1. **Thanet Beds.** — Light-coloured quartzose sand, mixed in the lower beds with much argillaceous matter, but never passing into actual clay; containing occasionally dark green grains, like those mentioned before in the Greensands. It rests almost invariably on a stratum of chalk flints, from which the chalk seems to have been washed away without wearing or fracturing the flints, and these are of a bright olive colour externally, by which they may be recognised in other beds (tertiary or drift) to which they may have been subsequently carried. The Thanet sands are very constant in character from the Isle of Thanet throughout the London basin, but thin out to the westward, till a little west of London they are only four feet thick,

* The total thickness of the fluvio-marine strata of the Isle of Wight, reckoning from the base of the Headon series, will be from 500 to 560 feet.

† The beds which Mr. Prestwich doubtfully classed as "basement-bed of the London Clay" in Kent, have been treated as an uppermost division of this group, under the name of "Oldhaven Beds."—Whitaker, *Quart. Journ. Geol. Soc.* vol. xxii. p. 412. The division for which this name has been proposed consists of well-rounded flint-shingle (Blackheath, Bromley, etc)., fine sand, and locally a bed of sandy-brown ironstone (near Canterbury), and it is generally from 20 to 40 feet thick.

shortly beyond which the beds disappear entirely.* They are thickest in East Kent, where they are also more clayey, and contain fossils. They may be seen abundantly in the sand-pits and railway cuttings about Woolwich, on the west, and on the coast near the Reculvers, and in Pegwell Bay, on the east.

2. The Woolwich and Reading Series of Prestwich.—More variable in character than the Thanet Sands, and also more widely extended, becoming thicker from east to west, or in the opposite direction to the Thanet sands, and then again thinner farther west (in the London Basin).

On the east, near Herne Bay, we have in it—

	Feet.
c. Argillaceous greensand	12
b. Dark grey argillaceous sand, with nodules of iron pyrites	7
a. Light ash green and yellow sands	9
	28

At Blackheath it consists of—

Pebble beds	12
Brownish sand	2
Estuarine shells in laminated clay	6
Light green sandy clays	7
Light green sands with pebbles	6
	33

Near Reading the beds are—

e. Mottled, red, green, and bluish-grey plastic clay	20
d. Laminated yellow sands	2
c. Light grey and greenish sandy clay	4
b. Fine yellow sand	8
a. Greensand with *Ostræa Bellovacina*	2
	36

But these beds are more than 50 feet thick in other parts of the district, and are ever varying in their character.†

At Newhaven, in Sussex, an outlier of the Hampshire district—

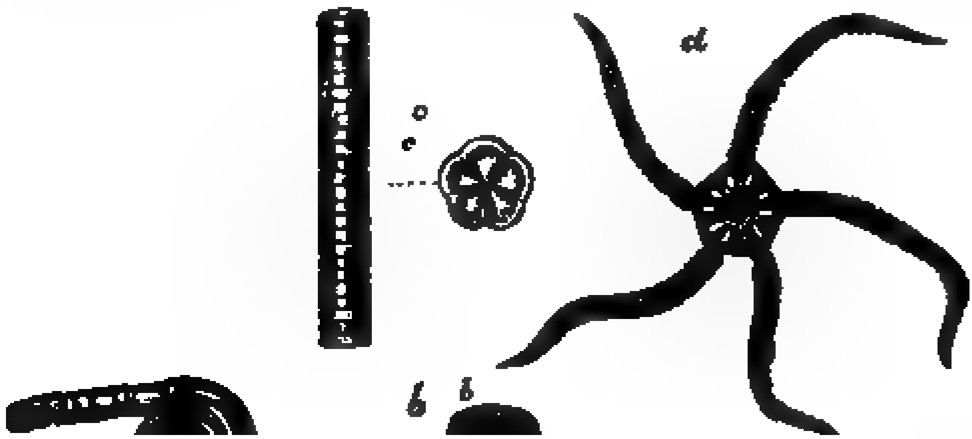
	Feet.
i. Grey clay and dark yellow sand	12
h. Round flint pebbles in grey clay and yellow sand	1
g. Laminated grey clay with seams of yellow sand	8
f. Concreted oyster rock (*O. Bellovacina*)	2
e. Comminuted shells in yellow sand and grey clay	6
d. Yellow, brown, and red sand, in layers	5
c. Dark grey clays with ironstone	20
b. White, ochreous, and green sand	25
a. Green and ferruginous-coated flints in sand	2
	81

* Prestwich, *Quart. Journ. Geol. Soc.* vol. viii. p. 235.

† For details, see Mr. Prestwich's paper, *Quart. Journ. Geol. Soc.* vol. x. p. 75; Whitaker, *Ib.* vol. xxii., and Geological Survey Memoirs on Sheets 7, 12, and 13.

In Alum Bay, Isle of Wight, these beds are 140 feet thick, consisting of bright-coloured tenacious mottled clays, the prevailing colour being blood-red, but having mixtures of light bluish grey and yellow, light and dark slate colour, lavender, puce, yellow and brown, almost free from any admixture of sand.

The Druid Sandstones, Grey wethers, Sarsenstones, and Puddingstones, scattered in loose blocks over many of the Chalk downs around the London basin, are believed by Mr. Prestwich * to be consolidated



Fossil Group No. 40.—Lower Eocene Fossils.

a. Nipadites umbonatus.
b. Paracyathus caryophyllus.
c. Pentacrinus sub-basaltiformis.
d. Ophiura Wetherellii.
e. Vermicularia Bognoriensis.
f. Hoploparia Bellii.
g. Zanthopsis tuberculata.

portions of the sands and gravels of the Woolwich and Reading series, but it is probable that they may in part have come from the Bagshot Sand †

3. The London Clay.—In the London basin this consists of—

b. Dark grey and brown clay, with layers of septaria or cement-stones, varying from a few feet or less on the west to 480 feet on the east, about Sheppey.

* *Quart. Journ. Geol. Soc.* vol. x.

† *Ibid.* vol. xviii.; also *Catalogue of Rock Specimens in Jermyn Street Museum.*

a. Basement-bed, brown, green, and ferruginous clayey sands, and occasionally clays with layers of flint-pebbles, having a maximum thickness of about 12 feet, and resting on the slightly eroded surface of the beds below.

In the Hampshire basin we have—

b. Dark blue clays and sands, containing nodules of argillaceous ironstone with bands of grey clayey sands and dark-greenish sands, sometimes compacted into hard stone called Bognor rock, having a total thickness varying from 193 to 363 feet.

a. Basement-bed of sand and clay, with a conglomerate of flint pebbles and partly-rounded fragments of chalk (or whitened flint), and of the mottled clays below, 4 to 5 feet.

Fossil Group No. 41.—Lower Eocene Fossils.

a. Terebratulina striatula. *b.* Pinna affinis. *c.* Cyrena cuneiformis. *d.* Cryptodon angulatum. *e.* Voluta Wetherellii. *f.* Aporrhais Sowerbii. *g.* Nautilus imperialis. *h.* Cœlopoma Colei. *i.* Lamna elegans. *j.* Otodus obliquus.

Characteristic Fossils of the Lower Eocenes.

Each of the groups now described has in reality a characteristic assemblage of fossils, many of which are peculiar to the group, while others are more abundant in it than elsewhere. The groups are also

linked together by fossils which range from one group into that above, or into still higher beds. In the first edition of this work, lists of the characteristic fossils of each group were given, and also those which were common to two or more groups. Time and space, however, alike forbid the revision of these lists, and compel me to substitute for them the following list of characteristic fossils of the Lower Eocene beds taken together :—

Plants . . .	Hightia elegans	Bow. Foss. Fr.*
	Leguminosites, several species . .	*Ibid.*
	Nipadites umbonatus	Foss. gr. 40, *a.*
	Wetherellia variabilis	Bow. Foss. Fr.
Foraminifera	Cristellaria Wetherellii	Q. J. G. S. viii.
	Dentalina acuta	D'Orbigny.
Actinozoa . .	Dasmia Sowerbyi	Br. Foss. Cor.
	Paracyathus caryophyllus . .	Foss. gr. 40, *b.*
Echinodermata	Astropecten crispatus	M. G. S., Dec. 1.
	Goniaster Stokesii	*Ibid.*
	Ophiura Wetherellii	Foss. gr. 40, *d.*
	Pentacrinus sub-basaltiformis . .	*Ibid.* 40, *c.*
Annelida . .	Vermicularia Bognoriensis . .	*Ibid.* 40, *e.*
Crustacea . .	Hoploparia Bellii	*Ibid.* 40, *f.*
	Zanthopsis tuberculata	*Ibid.* 40, *g.*
Polyzoa . .	Eschara Brongniarti	Dix. Foss. Suss.
	Flustra crassa.	
Brachiopoda .	Lingula tenuis	Sow. M. C. 19.
	Terebratulina striatula	Foss. gr. 41, *a.*
Conchifera .	Cryptodon angulatum	*Ibid.* 41, *d.*
	Cyprina planata	Sow. M. C. 619.
	Cyrena cuneiformis	Foss. gr. 41, *c.*
	Nucula Bowerbankii	Geol. Tr. vol. v.
	Ostræa Bellovacina	Sow. M. C. 388.
	Pholadomya margaritacea . . .	*Ibid.* 297.
	Pinna affinis	Foss. gr. 41, *b.*
	Syndosmya splendens	Tab. View.
	Teredo antenautæ	Sow. M. C. 102.
Gasteropoda .	Aporrhais Sowerbii	Foss. gr. 41, *f.*
	Cassidaria Smithii	Sow. M. C. 578.
	Cerithium funatum	*Ibid.* 147.
	Cypræa oviformis	*Ibid.* 4.
	Melania inquinata	Ly. Man. fig. 263.
	Trophon subnodosum	Q. J. G. S. viii.
	Voluta Wetherellii	Foss. gr. 41, *e.*
Cephalopoda .	Belosepia sepioidea	Ly. Man. fig. 255.
	Nautilus imperialis	Foss. gr. 41, *g.*
Fish . . .	Cœlopoma Colei	*Ibid.* 41, *h.*
	Lamna elegans	*Ibid.* 41, *i.*
	Otodus obliquus	*Ibid.* 41, *j.*
Reptiles . .	Chelone breviceps	Owen, Foss. Rep.
	Crocodilus champsoides . . .	*Ibid.*
	Palæophis toliapicus	*Ibid.*

* Bowerbank's *Fossil Fruits of the London Clay.*

Birds . . .	Halcyornis toliapicus	Owen, Foss. Mam.
	Lithornis Vulturensis	*Ibid.*
Mammals . .	Coryphodon Eocænus	*Ibid.*
	Didelphys Colchesteri	*Ibid.*
	Hyracotherium leporinum . .	Geol. Tr. vol. vi.
	Macacus Eocænus	Owen, Foss. Man.
	Pliolophus vulpiceps	Owen, Palæontology.

The Middle Eocene Groups.

4. **The Bagshot Series** takes its name from Bagshot Heath, but is best seen (in section) in the Isle of Wight. It consists of four groups, namely :—

4*a*. The Lower Bagshot Beds, composed of alternations of sand and clay ; the sands generally pale yellow or grey, but sometimes dark and ferruginous, at others fawn-coloured or rose coloured ; the clays are white pipe-clay, or grey, or chocolate-coloured and black clay. Thickness, 660 feet.

MIDDLE BAGSHOT.

4*b*. The Bracklesham Beds, so called from Bracklesham, on the coast of Sussex, dark chocolate-coloured marls and carbonaceous clays below, over which are whitish marly clay and white and greenish sands capped by a band of conglomerate of flint pebbles. Thickness 110 feet.

4*c*. The Barton Beds, greenish-grey sandy clay below, passing up into bluish-green and brown clay, interstratified occasionally with beds of sand and loam. Thickness 300 feet. This was formerly supposed to be the London clay.

4*d*. Upper Bagshot Beds, yellow and white sands with ferruginous stains. Occasionally 120 feet.*

5. **The Headon Series.**—All the Eocene beds described in the preceding pages, except part of the Woolwich and Reading series, are of marine origin. With the commencement of the Headon series, however, we meet with indications of fresh water having prevailed over what is now the Hampshire area, as well as at the corresponding period of the Paris tertiaries. In the London area no beds higher than the Bagshots are known.

5*a*. The Lower Headon Beds consist of 31 feet of clays and marls in Whitecliff Bay, while at Headon Hill and Colwell Bay they contain thick limestones, and are from 60 to 80 feet thick, and they are still more varied at Hordwell on the opposite coast of Hampshire. They are the "Lower Freshwater formation" of Webster.

5*b*. The Middle Headon Beds consist principally of sands, showing at Headon Hill brackish water fossils, but containing beds of oysters ; while at Colwell Bay and Hordwell, and still more strongly at Whitecliff Bay, the beds have a purely marine character. Webster called them the "Upper Marine formation." At Colwell Bay they are only 23 feet thick, but at Whitecliff Bay they swell out to 100 feet.

5*c*. The Upper Headon Beds contain the strongest limestones of Headon Hill,

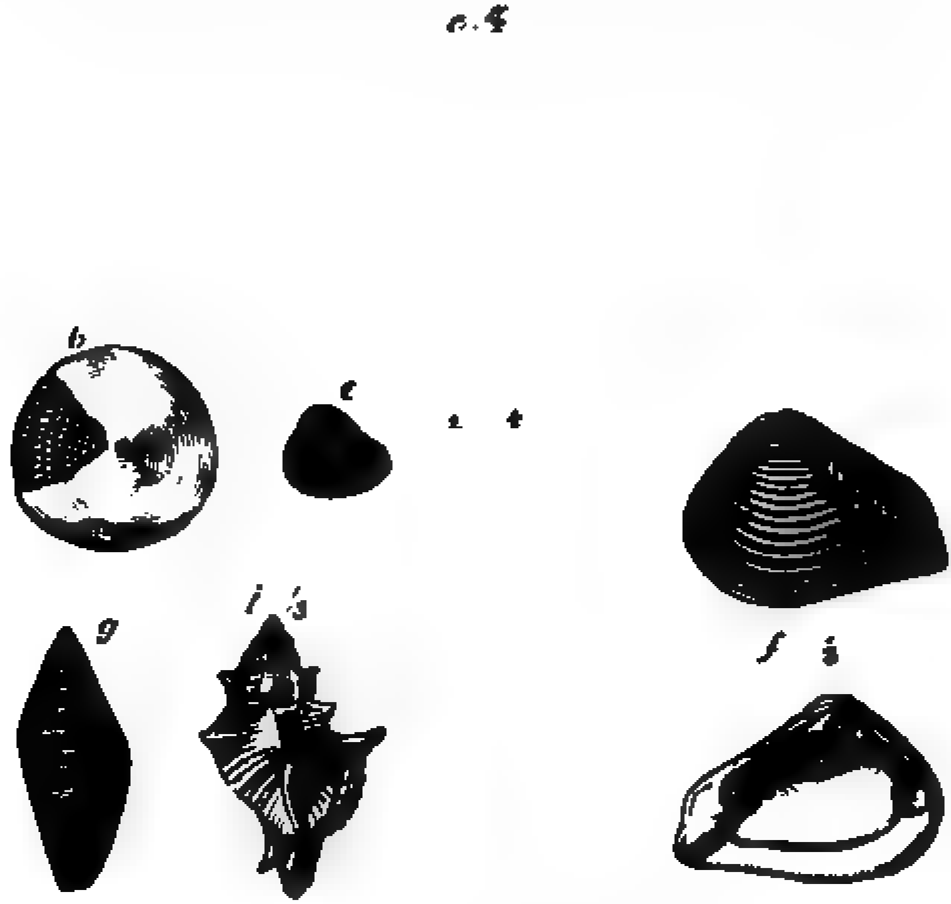
* Mr. Bristow's Section in *Mems. Geol. Survey*, 1856 ; Forbes's *Isle of Wight*, in same Memoirs. See also Prestwich, *Quart. Journ. Geol. Soc.*, vol. ii. p. 258, and vol. xiii. p. 99.

where they are 85 feet thick, thinning out rapidly towards the north. They are represented by a few very thin and inconspicuous sandy concretionary bands, with a total thickness of only 44 feet in Whitecliff Bay. The uppermost beds of the group are marls. Webster gave the name of "Upper Freshwater formation" to this group.

6. **Osborne Series.**—This series varies from 50 feet in Headon Hill to 80 feet at Whitecliff Bay. It is divisible into two groups.

6*a*. The Nettlestone Grits consist of hard rag and shelly sandstone below, capped by marl and bright yellow limestone. The whole about 20 feet in thickness in some places, but in others thinning out and disappearing, or becoming a mere loose sand.

6*b*. The St. Helen's Sands, or uppermost part of the Osborne series, consist of an alteration of white, and green, and yellow sands, with blue, white, and yellowish clays and marls, having a total thickness of about 50 feet.



Fossil Group No. 42.—Middle Eocene Fossils.

a. Litharea Websteri.	*d.* Chama squamosa.	*g.* Conus dormitor.
b. Nummulites lævigatus.	*e.* Corbula pisum.	*h.* Fusus longævus.
c. Ostræa flabellula.	*f.* Crassatella sulcata.	*i.* Murex asper.

Characteristic Fossils of the Middle Eocene Groups.

Some of the beds just described contain in many places an enormous abundance of fossils, often in the highest state of preservation. Each

group and each sub-group has fossils peculiar to itself, as well as others common to it and to one or more other groups. The Barton Clays on the coast of Dorsetshire and Hampshire, and the Bracklesham beds of the Sussex coast, are literally crowded with beautiful shells, of which a magnificent series may now be seen in the cases of the Museum of

Fossil Group No. 43.
Middle Eocene Fossils.

a. Pleurotoma colon.	*f.* Natica ambulacrum.
b. Rostellaria rimosa.	*g.* Cancellaria evulsa.
c. Strombus Bartonensis.	*h.* Oliva Branderi.
d. Voluta scabricula.	*i.* Ancillaria buccinoides.
e. Voluta luctatrix.	*j.* Dentalium striatum.

Practical Geology in Jermyn Street. The following list contains a very meagre and imperfect selection from the completer lists of Middle Eocene fossils; the numbers prefixed referring to the groups of strata in which the species are found.

Plants . . .	6. Chara Lyellii	Geol. Tr., vol. ii.
	4*b*. Comptonia dryandrifolia . . .	Brongniart.
	4*a*. Leaves of trees beautifully preserved in pipe-clay.	
Foraminifera	4*b*. Nummulites lævigatus . . .	Foss. gr. 42, *b*.
	4*b*. Quinqueloculina Hauerina . .	Dix. Foss. Suss.
	4*b*. Rotalina obscura	*Ibid.*
	4*c*. Triloculina cor-anguinum . .	*Ibid.*

Actinozoa	4*b*. Litharea Websteri	Foss. gr. 42, *a*.
	4*c*. Turbinolia Bowerbankii	Br. Foss. Cor.
Echinodermata	4*c*. Eupatagus Hastingsiæ	Tert. Ech.,* 26.
Brachiopoda	4*c*. Terebratula bisinuata	Dav. Brach.
Conchifera	4 *b* and *c*. Arca Branderi	Tab. View.
	4*b*. Cardita (Venericardia) planicosta	*Ibid.*
	4*c*. Chama squamosa	Foss. gr. 42, *d*.
	4 *b* and *c*. Corbula pisum	*Ibid.* 42, *e*.
	4*c*. Crassatella sulcata	*Ibid.* 42, *f*.
	4 *b* and *c*. Ostræa flabellula	*Ibid.* 42, *c*.
	5. Potamomya gregaria	Sow. M. C., 363.
Gasteropoda	4 *b* and *c*. Ancillaria buccinoides	Foss. gr. 43, *i*.
	4 *b* and *c*. Cancellaria evulsa	*Ibid.* 43, *g*.
	4*c*. Conus dormitor	*Ibid.* 42, *g*.
	4 *b* and *c*. Dentalium striatum	*Ibid.* 43, *j*.
	4 *b* and *c*. Fusus longævus	*Ibid.* 42, *h*.
	5, 6, and 7. Limnæa longiscata	*Ibid.* 44, *i*.
	5. Melanopsis subfusiformis.	
	4*c*. Mitra scabra	Sow. M. C., 401.
	4 *b* and *c*. Murex asper	Foss. gr. 42, *i*.
	4 *b* and *c*. Natica ambulacrum	*Ibid.* 43, *f*.
	4*c*. Oliva Branderi	*Ibid.* 43, *h*.
	5 and 6. Planorbis euomphalus	Tab. View.
	? Pleurotoma colon	Foss. gr. 43, *a*.
	5. Potamides (Cerithium) concavus	Sow. M.C., 339.
	4*c*. Rostellaria rimosa	Foss. gr. 43, *b*.
	4*c*. Strombus Bartonensis	*Ibid.* 43, *c*.
	4*c*. Trochus monilifer	Sow. M. C., 367.
	4*c*. Typhis pungens	Tab. View.
	4 *b* and *c*. Voluta luctatrix	Foss. gr. 43, *e*.
	——— scabricula	*Ibid.* 43, *d*.
Cephalopoda	4*b*. Beloptera belemnitoidea	Dix. Foss. Suss.
Fish	4*b*. Edaphodon Bucklandi	Agassiz.
	4*b*. Myliobatis Edwardsii	Dix. Foss. Suss.
Reptiles	4*c*. Alligator Hantoniensis	Owen, Foss. Rep.
	4*c*. Crocodilus Hastingsiæ	*Ibid.*
	4*b*. Gavialis Dixoni	*Ibid.*
	4*b*. Palæophis Typhæus	*Ibid.*
Mammalia	5. Dichodon cuspidatus	Q. J. G. S., iv.
	4*b*. Lophiodon minimus	Owen, Foss. Mam.
	5. Microchœrus erinaceus	Q. J. G. S., vol. ii.
	5. Paloplotherium annectens	*Ibid.* vol. iv.

The Upper Eocene Groups.

The fluvio-marine conditions are still continued in the Isle of Wight district, without any very marked line of distinction, between the top of the Middle and the base of the Upper Eocene groups.

7. **The Bembridge Series** contains the following subdivisions, beginning with the lowest :—

7*a*. The Bembridge Limestone. A pale yellow or cream-coloured limestone,

* Forbes's *Tertiary Echinodermata*, Pal. Soc.

interstratified with clay or crumbling marl—the limestone full of cavities, and often quite tufaceous and concretionary, sometimes a true travertine, and sometimes conglomeratic; contains siliceous or cherty bands in some places. Thickness, 20 to 25 feet.

7*b.* The Oyster bed. A few feet of greenish sands containing oysters (*Ostrea Vectensis*) in great abundance, capped by a band of hard septarian stone, which is constant over a large area. About 10 feet altogether.

7*c.* Unfossiliferous mottled clays, alternating with fossiliferous laminated clays and marls containing *Cyrena pulchra.*

7*d.* Marls and laminated grey clays, containing *Melania turritissima.* Capped by the "Black Band," forming the base of the Hempstead series.

Fossil Group No. 44.
Upper Eocene Fossils.

a. Chara medicaginula.
b. Cyrena pulchra.
c. Achatina costellata.
d. Paludina orbicularis.
e. Bulimus ellipticus.
f. Helix D'Urbani.
g. Hydrobia Chastelii.
h. Carithium elegans.
i. Limnæa longiscata.

8. **The Hempstead Series.***—The three lower divisions of fresh-water and estuary origin.

* Sir Charles Lyell separates this series from the Eocene, and classes it as Lower Miocene.

8*a*. Black Band and marls. The lowest bed of this group is a firm carbonaceous laminated clay, highly fossiliferous, about 2 feet thick, known as the "Black Band," over which are pale bluish and yellow shaly marls, with ironstone concretions. The whole about 40 feet thick.

8*b*. White Band, marls and clays. The base of this group, called the "White Band," is a bed of mingled broken and entire shells, more or less consolidated, often very ferruginous, from 6 inches to two feet thick, over which are mottled, yellow, and pale green marls, capped by shaly clays and dark marls, and blue green ferruginous clays, with ironstone concretions. Total thickness about 50 feet.

8*c*. Variegated red and green marls and grey clays, covered by greenish clay, passing up into pale and dark grey or lead-coloured clays. Thickness about 40 feet.

8*d*. Clays with septaria, and grey and bluish clays with concretions containing abundance of *Corbula*; marine. About 25 feet thick.

Characteristic Fossils of the Upper Eocene Beds.

Plants . . .	7 and 8. Chara medicaginula .	Foss. gr. 44, *a*.
	Flabellaria Lamanonis . .	Brongniart.
Conchifera . .	8*d*. Corbula Vectensis . .	Forbes, I. of W., pl. 1.*
	7*c*. Cyrena pulchra . .	Foss. gr. 44, *b*.
	7*b*. Ostræa Vectensis . .	Forbes, I. of W., pl. 3.
Gasteropoda .	7. Achatina costellata . .	Foss. gr. 44, *c*.
	7. Bulimus ellipticus . .	*Ibid.* 44, *e*.
	8. Cerithium elegans . .	*Ibid.* 44, *h*.
	7. Helix D'Urbani . .	*Ibid.* 44, *j*
	8. Hydrobia Chastellii . .	*Ibid.* 44, *g*.
	7*a*. Melania turritissima . .	Ly. Man., fig. 211.
	7. Paludina orbicularis . .	Foss. gr. 44, *d*.
	7. Planorbis discus . .	Ly. Man., fig. 216.
	8. Voluta Rathieri . .	Ed. Eoc. Mol.†
Reptiles . .	8. Trionyx incrassatus . .	Owen, Foss. Rep.
Mammalia .	7. Anoplotherium commune .	Ly. Man., fig. 219.
	7. Chœropotamus Cuvieri .	Geol. Trans., vol. vi.
	7. Dichobune cervinum . .	*Ibid.* vol. vi.
	8. Hyopotamus bovinus .	Q. J. G. S., vol. iv.
	7. ———— Vectensis	*Ibid.*
	7. Palæotherium crassum .	Geol. Trans., vol. vi.
	8. ————magnum . .	Ly. Man., fig. 220.

Foreign Localities.

France and Belgium.—The labours of Mr. Prestwich, continued so long and assiduously, have gradually made plain to us the correlation of the English and French Eocene beds, and, joined with those of Sir C. Lyell and M. Dumont, have also taught us the relation of these with those of Belgium. The following Table exhibits these relations as they are now believed to be, taking Mr. Prestwich's

* Forbes's "Isle of Wight," in *Memoirs of the Geological Survey.*
† Edwards's "Eocene Mollusca,"—*Pal. Soc.*

classification for all below the Upper Bagshot Sands, and Professor Edward Forbes's for those and all above them :—

England.	Belgium.	France.
11. Hempstead .	Rupelien . .	Calcaire de la Beauce. Grès de Fontainebleau. Sables et bancs de coquilles, marnes marines.
10. Bembridge .	Tongrien . .	Calcaire siliceux, calcaire lacustre moyenne, Gypseous series of Montmartre, etc.
9. Osborne, 8. Headon .	Laeckenien, part of ?	Calcaire marin et Grès de Beauchamp.
7. Upper Bagshot	Système Laeckenien supérieur ? .	Sables moyennes, upper zone.
6. Barton Clay .	Système Laeckenien inferieur ? . .	Sables moyennes, lower zone.
5. Bracklesham .	Système Bruxellien	Calcaire grossier,* and Glauconie grossière.
4. Lower Bagshot Beds . .	Système Ypresien supérieur . .	Lits coquillières, and Glauconie moyenne.
3. London Clay .	Système Ypresien inférieur . .	Wanting.†
2. Woolwich and Reading Beds	Système Landenien supérieur. .	Grès de Poudingues, Lignites et Argile Plastique, Glauconie inférieur.
1. Thanet Sands	Système Landenien inferieur . .	Wanting.

According to Mr. Prestwich, the London Tertiaries were deposited in a sea open to the north, spreading at least over south-east England, Belgium, and north of France, whilst to the south of that area dry land prevailed over the great part of the Paris Tertiary district and still farther south. Gradual depression then

* Mr. Prestwich gives (*Quart. Journ. Geol. Soc.*, vol. xiii. p. 99) the following detailed description of the calcaire grossier :—

	Feet.
4. Compact white marls, passing down into alternations of greenish marls and thin yellow limestones, with seams of chert	20
3. Thin bedded fissile calcareous flags and sandstones, alternating with white marls and limestones	15
2. Thick main mass of soft, light-yellow calcareous freestone (the building stone of Paris got by mining or subterranean quarrying) passing sometimes into calcareous sands	40
1. Variable, more or less calcareous, green sands, sometimes concreted, flint pebbles often at base	25
	100

† Some part of it, however, formerly extended into Normandy, as some clay at the top of the cliff of Ailly, near Dieppe, is believed to be London Clay. (Prestwich, *Quart. Journ. Geol. Soc.*, vol. xi. p. 230.)

took place, extending the limits of the sea over the Paris area, leading to the introduction of Nummulites and more southern forms of marine life than had hitherto prevailed. Dry land was still in the immediate neighbourhood, as shown by the occasional presence of terrestrial forms, and alternations of elevation and depression doubtless took place, modifying here and there the physical geography of the district. The Barton Clay, for instance, seems to have been deposited in a sea of a more northern character than that in which the Bracklesham clays and sand were formed. Fresh-water conditions finally became prevalent, large estuaries opened into the seas over the British and north of France areas, while large lakes existed in the centre and south of France, where, soon after, volcanic eruptions commenced to break forth, and continued for many thousand years in subsequent periods. Edward Forbes pointed out that the upper part of the Bembridge series was probably of the same age as the Molasse of Fronsadais and associated beds, and also as the Calcaire à Astéries of the south-west of France; part of the Tertiary beds of Malta, Corsica, Greece, Crete, Cerigo, south of Spain and Portugal, Azores, and North Africa, were also considered to be contemporaneous with the Hempstead series. Contemporaneous with the Hempstead also were the Molasse ossifère and the Faluns jaunes of Dax, the lower division of the Vienna Tertiaries and the marine beds, the Cerithium Kalk and Upper Brown Coal of Mayence.*

Sir C. Lyell, however, thinks that it would be more convenient to retain a nomenclature common on the Continent, and to class the Hempstead series and its contemporaneous beds as Lower Miocene, making the beds from the Barton Clay to the Bembridge series inclusive Upper Eocene, and taking the Bracklesham and Lower Bagshot beds only as Middle Eocene.† Certainly, as far as England (Isle of Wight) is concerned, the Hempstead beds are linked to those below by almost as great a number of species as they have peculiar to themselves.

The Alps, the Borders of the Mediterranean, Egypt, India.—Through these countries from the Alps to the Himalayas, occurring at intervals through 25° of lat. and near 100° of long., are found great masses of rock, sometimes even thousands of feet in thickness, crowded with nummulites, and often almost made up of them. These are of Middle Eocene age. The summits of some of the Alps, such as the Dent du Midi and Diableretz, are formed of these beds. Associated with these are still higher beds called Flysch and Macigno in Switzerland and North Italy, and the black slates or shales of Glarus, and other beds in Switzerland, containing quantities of fossil fish, etc. The Monte Bolca fish-beds are also of about this age.‡ The Eocene beds of the Alps are not only of as great a thickness, but are as violently disturbed and contorted, and as frequently inverted, as are the older Palæozoic rocks in the mountains of Britain.

M. Alcide D'Orbigny uses the name of Suessonien (from the town of Soissons) to include the Lower Eocene beds, from which, however, he excludes the London Clay, but includes the Nummulitic formation. He also gives the designation of Parisien to the London Clay of England and the Paris tertiaries, from the Glauconie grossière to the gypsum beds of Montmartre—a classification which Mr. Prestwich has shown to be a mistake. D'Orbigny then takes the Grès de Fontainebleau as the base of his twenty-sixth stage, which he calls Falunien, subdividing it into two—Lower Falunien or Tongrien, to which he assigns the Grès de Fontainebleau, and Upper or Falunien proper, which he identifies at the same time with the Miocene of Lyell, and the Crag, which is believed to be Pliocene.

North America.—Sir C. Lyell places the Claiborne and Alabama beds among the productions of the Middle Eocene period.

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* *Memoirs of Geol. Survey*, 1856, p. 100. † *Manual*, p. 237.

‡ Murchison, *Geol. Journ.*, vol. v. p. 157, etc.

CHAPTER XXXIX.

MIOCENE PERIOD.

THE proportion of living to extinct species in the deposits of this period is taken at about 25 per cent, without strictly adhering to that proportion. If we include the Hempstead series in the deposits of the Eocene period, as was done in the previous chapter, we have no stratified rocks in the British Islands representative of the formations of the Miocene period except the lignite of Bovey Tracey and the leaf-beds of Mull and Antrim.

At Bovey Tracey, in Devonshire, a small patch of fluviatile or lacustrine strata, containing beds of lignite, has long been known. These have recently been investigated, and are now known to be about 300 feet in depth, consisting of alternations of clay, sand, and lignite. Numerous well-preserved fossil plants, amounting in all to about fifty species, have been obtained from these beds. They indicate a warm climate, and are analogous to the older Miocene vegetation of Switzerland. Among them may be mentioned ferns and fragments of species of *Sequoia*, palm, vine, oak, laurel, fig, etc.*

At Ardtun, in the Island of Mull, several layers of tuff and clay occur, interstratified among the basalt beds of that locality. They were first brought to notice by the Duke of Argyll, as containing the remains of dicotyledonous plants.† The headland of Ardtun exhibits the following section of these deposits :—

	Feet.
8. Uppermost basalt	40
7. First "leaf-bed"	2
6. First tuff	20
5. Second "leaf-bed"	2½
4. Second tuff	7
3. Third "leaf-bed"	1½
2. Amorphous basalt	48
1. Columnar basalt (to low-tide level) . .	10
	131

These tuffs are described as resembling those of Mont Dor, Vesuvius, and Madeira ; the leaf-beds as baked clay, or very fine mud, con-

* See Mr. Pengelly's *Lignite Formation of Bovey Tracey*, London, 1863 ; also a paper by him and Professor Heer in the *Phil. Trans.* for 1863.

† See *Quart. Journ. Geol. Soc.* vol. vii.

taining impressions of leaves, and sometimes consisting of a mere mass of compressed leaves still retaining the "damp obscure colours of vegetable decay." Equiseta stems occur as well as the leaves, and the whole deposits are conjectured to have been formed in a shallow lake or marsh, over which the igneous rocks have been ejected. A conglomerate of burnt red and yellow Chalk flints is mentioned as associated in one place with the first tuff (No. 6).

The leaves were examined by Professor Edward Forbes, who says

Fossil Group No. 46.—Fossil leaves from Island of Mull.

a. Filicites Hebridica. b. Alnites? Macquarii. c. Rhamnites? multinervatus.

of them:—"The general assemblage of leaves is decidedly Tertiary, and most probably of that stage of Tertiary termed Miocene. Their climatal aspect is more mid-European than that of our Eocene flora. There is a striking resemblance between some of them and fossils from Styria and Croatia." * Professor Heer, who has studied the Swiss Miocene flora with great care, confirms this decision, and recognises among the Hebridean forms *Sequoia Langsdorfii* and *Corylus grosse-dentata*, plants found in the Miocene deposits of Switzerland.

* *Op. cit.*

It was supposed by the Duke of Argyll that the leaf-beds and their associated basalts were a mere local exhibition of Miocene rocks. Mr. Geikie has more recently, however, shown that these leaf-beds in reality lie at the base, or nearly at the base, of the whole of the volcanic rocks of Mull, and that these rocks, more than 3000 feet thick, as well as the other volcanic plateaux of the Inner Hebrides, are not of Oolitic age, as had been previously supposed, but all date from the Miocene period. In Mull, and in Skye, beds of coal occur interstratified among the sheets of basalt. These too are Miocene, and are sometimes black, glossy, and cubical, quite undistinguishable to the eye from ordinary carboniferous coal.*

The general resemblance between the basaltic plateaux of the Inner Hebrides and of the north-east of Ireland has long been known. Over the Chalk in Antrim there is a thickness of nearly 500 feet of beds of basalt, with occasional bands of tuff and clay. In one of these interstratified deposits, at Ballypalady, near Antrim, a leaf-bed has recently been found containing leaves of dicotyledonous trees, believed to be of Miocene age, and occurring under very similar conditions to those of the Island of Mull.†

These are the only rocks in the British Islands that can be even conjectured to belong to the Miocene period, unless we adopt the Continental classification, and consider the gypseous series of Montmartre the uppermost of the Eocene beds, in which case we must also take the equivalent Bembridge series of the Isle of Wight as the uppermost of the Eocene, and include the Hempstead beds and their equivalents among the Miocene deposits. There is, it appears, a palæontological reason for this arrangement on the Continent, inasmuch as, if we draw the line at the top of the Montmartre beds, and at the base of the Calcaire lacustre supérieur (or Calcaire de la Beauce), certain generic and even specific forms of Mammalia are kept wholly within the Miocene groups, which otherwise would be made common to the Eocene and Miocene periods. The genera *Dorcatherium*, *Cainotherium*, *Anchitherium*, and *Titanomys*, and the species *Rhinoceros incisivus*, and others, are examples.

VOLCANIC ROCKS OF MIOCENE AGE IN BRITAIN.

By far the most extensive and interesting series of rocks of this period in Britain are of volcanic origin. From the south of Antrim northwards, through the chain of the Inner Hebrides to the Faroe Islands, and even to Iceland, there stretches a long broken series of basaltic plateaux, which, from the character of the plant-remains found in them, and from their position above the Chalk, are referred to the Miocene period.‡

* See Geikie, *Proc. Roy. Soc. Edin.*, vol. 1866-7. † *Journ. Geol. Soc.* (1869), vol. xxv. p. 357.

‡ The following notice of these rocks is by Mr. Geikie.

"The two great classes of recent lavas—the basaltic and the felspathic—are well represented among the Western Islands. The basaltic series is on the whole the older, since it is found to pass under massive sheets of pale grey and blue clay-stones, clinkstones, and porphyries belonging to the felspathic group. In addition to these lava-form rocks, masses of coarse volcanic agglomerate occur, along with beds of tuff and peperino.

"The leaf-beds of Ardtun, which are known by their fossil contents to be of Miocene age, lie near the bottom of the whole volcanic series of the Hebrides, and above them comes a succession of sheets of basalt, etc., between 3000 and 4000 feet in thickness. Throughout this enormous mass of bedded igneous rock, layers of tuff, often abounding in chalk-flints, are interstratified, and in one part of the cliffs of Inimore of Carsaig a bed of flints twenty-five feet thick lies between the dolerites. Thin lenticular seams or nests of coal likewise occur, but these only occupy small pond-like hollows of the original surface of the basalts or dolerites, and are overlaid directly with similar rock. They are sometimes excellent in quality, and occasionally three feet in thickness; but they rapidly die out in every direction. There is thus no probability that the tertiary coal of the Western Islands will ever come to be of commercial importance.

"Proofs of the long continuance of volcanic action among these islands are afforded by the great thickness of the successive sheets of igneous matter, which in one mountain alone—Ben More in Mull—reach a depth of 3185 feet, without revealing either the actual bottom or top of the series. Another and striking piece of evidence on this subject is given by the well-known Scùr of Eigg. That island consists of nearly horizontal sheets of basaltic rocks, like those of Mull, resting unconformably upon Oolitic rocks. After their eruption, they must have been long exposed to the wasting agencies of the atmosphere. A valley was cut out of them, and its bottom was watered by a river, which brought down coarse shingle and sand from the distant Cambrian mountains of the north-west. These changes must have demanded a lengthened lapse of time, yet they took place during an interval in the volcanic history of the island. The igneous forces which had been long dormant broke out anew, and poured several successive *coulées* of vitreous lava (pitchstone) down the river-bed. In this way the channel of the stream came to be sealed up. But the same powers of waste which had scooped out that channel continued their operation. The hills which had bounded the valley crumbled away, and the lava-currents that filled the river-bed, being much harder than the surrounding rocks, were enabled in great measure to resist the degradation. Hence the singular result now appears that the former hills have been levelled down into slopes and valleys, while the ancient valley occupies the highest ground in the neighbourhood, and its lava-current stands up as the well-

known precipitous ridge of the Scùr of Eigg. The gravel and drift-wood of the old river are still to be seen under the rock of the Scùr."

In connection with this development of volcanic activity, the author now quoted has called attention to "the possible connection between these Tertiary volcanic rocks and the metamorphism of different parts of the West Highlands. In Mull, under Ben More, the volcanic rocks themselves give signs of having been subjected to a process of metamorphism, and they are associated there with masses of syenite, like those of Raasay and Skye. Macculloch pointed out that the syenite of the two latter islands was later than the secondary rocks of that district; and there now seems to be a strong probability that it will turn out to be of Miocene age. Parts of that syenite are a quartz-porphyry, other portions seem to pass into a true granite, while the Lias around it has suffered an extensive metamorphism. It will be an important addition to our knowledge of the history of metamorphic action, if the alteration of the secondary rocks of the Hebrides is eventually shown to be connected with the evolution of volcanic rocks during the Miocene period."

The wide extent to which the British Islands were affected by the Miocene volcanoes of the west, is shown by the abundant trap-dykes, of which an account was given in Chapter XIII. "That extent is not to be measured by the area at present covered with Tertiary volcanic rocks, nor even by the area which these rocks may have originally overspread, but from which subsequent denudation has removed them. From the great volcanic ridge running through Antrim and the Western Islands, thousands of trap-dykes diverge in a south-easterly direction. They become fewer as the distance from that bank increases, yet they extend as far as the coast of Yorkshire. No single dyke, indeed, has been traced across the country from sea to sea, but there can be little doubt that they all belong to one series. They cut through all the formations up to and including the chalk, and they likewise traverse the older portions of the Tertiary volcanic rocks. They must thus be of Tertiary age, and belong to that of the great series of igneous masses now described. They do not usually run along lines of fault; on the contrary, they are found to cross faults of fifty fathoms and upwards without being deflected. Their evenness and parallelism show that they must have ascended through fissures prepared for them by subterranean movements. Thus we learn that in Tertiary times the greater part of Scotland, the north of England, and the north of Ireland, were cracked by earthquakes, and that liquid lava rose through the hundreds of parallel rents, perhaps in some cases actually reaching the surface.

"Comparatively recent as these Miocene volcanic rocks of the Hebrides are, they are old enough to have undergone enormous denudation. Wide, deep, and long valleys have been excavated out of

the horizontal trap-beds; and these rocks have sometimes been so wasted away that only huge detached pyramids of them are left, as in the case of Ben More, Mull. The volcanic bank which stretched through the Inner Hebrides has been worn down into detached islands, often miles apart. From the fact of so many trap-dykes reaching the surface, even at a distance of more than 200 miles from the main mass of volcanic rock, we can hardly avoid the inference that the general superficies of the country has undergone a very extensive amount of denudation since the Miocene period."*

The picturesque coast line of Antrim affords many admirable sections of these Miocene volcanic rocks. The basalt beds may there be seen rising in regular succession over each other from the base of the cliffs to their summit. Some of these beds are regularly columnar, with cup and ball articulations, others, like starch, irregularly columnar without articulations. Many consist of an amorphous green amygdaloidal, more or less decomposed rock, full of cavities and veins of zeolites. Interstratified between some of the basalts occur beds of tuff, some of which, very regular and persistent for a long distance, are seen in consequence of their being of lighter and brighter colours than the other rocks. They contain nodular concretions of red pisolitic oxide of iron, from which they are often spoken of as red ochre beds. Near the summit of the cliff over the Giant's Causeway, beneath a wall of rudely columnar basalt 50 feet high, is a little rather irregular seam of grey fire-clay, and in that or over it is an irregular band of coal or lignite, which Mr. Nasmyth says sometimes shows the fibres of dicotyledonous wood, like recent charcoal. Whole trees are said to be sometimes obtained from this bed.

Dr. Berger puts the maximum thickness of the Antrim basaltic formation at 900 feet, its average thickness being taken as 545 feet, and its extent at 800 square miles.† From Sir R. Griffith's map its area would appear to be at least 1200 square miles, as it occupies a quadrangular space 48 miles long from north to south, and 28 miles wide from east to west. In Fig. 165 we have a diagrammatic section through Cave Hill and across the valley of Belfast. In this section the basalt of the great plateau is seen resting on the Cretaceous beds. Just at the base of the basalt is a little bed of brown clay, full of chalk flints, burnt red or yellow. This appears to have been the muddy deposit derived from the waste of the chalk, and most probably to have formed the sea-bottom on which the first outpourings of igneous matter were deposited. I did not succeed in discovering any organic remains in it, but should hope that some may eventually be found, as leaves and other vegetable

* Geikie on Tertiary Volcanic Rocks of the British Islands. *Proc. Roy. Soc. Edin.* 1866-7; also a detailed Paper, the first of a series on the same subject, in *Quart. Journ. Geol. Soc.*, vol. xxvii.

† See *Trans. Geol. Soc.*, 1st ser. vol. iii.

fossils have now been found in some of the ash-beds. This clay is well seen also at Ballycastle, and doubtless occurs in other places.

The dykes represented in Fig. 165 are excessively numerous in the country about the basalt, both on the north coast and near Belfast, and

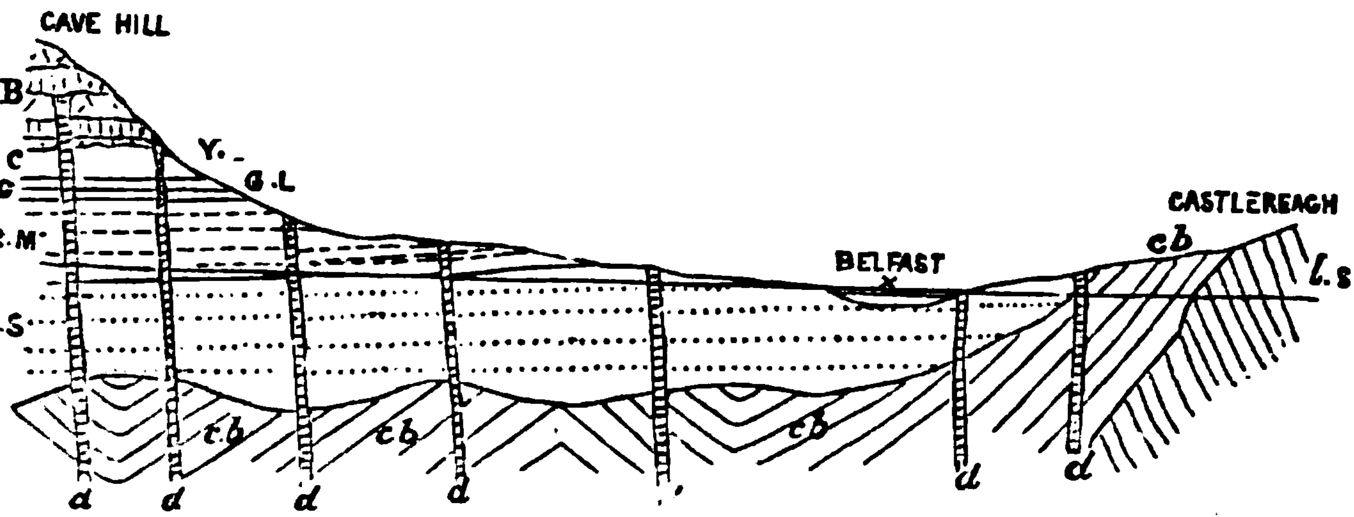

Fig. 165.

Diagrammatic Section across Belfast Valley.

		Feet.	
B.	Basalt, some columnar beds, some amygdaloidal . . .	up to 900	Tertiary.
Y.	Eroded surface of chalk, with clay full of flints baked by basalt.		
C.	Chalk	in some places as much as 250	Cretaceous.
G.	Greensand	not exceeding 25	
L.	Lias	never exceeding 30	Oolitic.
N. R. M.	New red marls, with beds of rock-salt . . .	about 600	Trias.
N. R. S.	New Red Sandstone	about 600	
c. b.	Carboniferous rocks, undulating at high angles, probably with small basins, some of which may contain beds of coal. The lower beds only visible on east side of the Lough.		
l. s.	Lower Silurian, black slates, etc., dipping at high angles to east, away from the Carboniferous rocks.		
d.	Dykes of basalt.		
×	Clay and silt, with bed of peat below, filling up head of Belfast Lough.		

probably in other parts. On the shores of Belfast Lough they form straight causeways, standing up as vertical walls, several feet high, exactly as if they were artificial quays. The slopes of the Cave Hill are traversed by dykes, some of which can be traced up from the coast and seen in the Chalk quarries, cutting in black vertical seams through the white limestone in a most picturesque manner. These dykes are probably in many cases the feeders from which some of the basaltic beds above may have boiled over while the rock was molten, though in other cases they may not perhaps have succeeded in reaching the surface.

Characteristic Fossils.—I shall not pretend to give lists of these. Sir C. Lyell says that the fossils of the "faluns" have a more extra-European facies than those of the Crag presently to be described. They contain seven species of *Cypræa*, some larger than any Mediterranean cowry, and several species of the genera *Oliva*, *Ancillaria*, *Mitra*, *Terebra*, *Pyrula*, *Fasciolaria*, and *Conus*. There are eight cones, some

very large, and the species of *Nerita* are more like those of the tropics than of the Mediterranean. Out of 290 species of shells collected by Sir C. Lyell to the south of Tours, 72 only could be identified as living species, which is about 25 per cent; among a total of 302 in his possession, 45 only are to be found in the Suffolk Crag, or 15 per cent; and a similar small percentage in the Actinozoa and Polyzoa. If we compared the fossils of the "faluns" with those of living British species, we should doubtless have very few in common, the living species found in the Faluns being to be sought in more tropical provinces, while those of the Crag have a more northern "facies" impressed upon them. The Faluns have a few terrestrial species of shells, among which is the *Helix Turonensis*, and remains of Mammalia belonging to the genera *Deinotherium*, *Mastodon*, *Hippopotamus*, *Chœropotamus*, *Dichobune*, Deer, and others, together with some Cetaceans and Phocidæ, Lamantine, Morse, etc. The very remarkable animal *Deinotherium giganteum* is characteristic of the Miocene beds of Europe; while another species, *D. Indicum*, has been found at Perim Island in the Gulf of Cambay, and at Attock in the Punjab.*

In the Sewalik Hills of India, Dr. Falconer and Colonel Cautley found, together with portions of Mastodon, five extinct elephants (three of them, *Stegodon*, intermediate between *Elephas* and *Mastodon*), a *Hexaprotodon* (extinct hippopotamus), a *Chalicotherium* (a rhinoceros-like pachyderm) and extinct Giraffe, a Camel and large Ostrich, the very remarkable genus *Sivatherium*, together with Carnivora and Monkeys, great Crocodiles, and a gigantic Tortoise (*Colossochelys Atlas*), the curved shell of which was upwards of 12 feet long and 8 feet broad. Fifteen species of fresh-water shells also occur, of which all but four are extinct, giving a percentage of about 25 : 100.†

In North America are many shells of the genera *Natica*, *Fissurella*, *Artemis*, *Lucina*, *Chama*, *Pectunculus*, and *Pecten*, and one, *Astarte undulata*, very like the *A. bipartita* of the Suffolk Crag. "Out of 147 of these American fossils," says Sir C. Lyell, "I could only find thirteen species common to Europe, and these occur partly in the Suffolk Crag and partly in the Faluns of Touraine; but it is an important characteristic of the American group that it not only contains many peculiar extinct forms, such as *Fusus quadricostatus* and *Venus tridacnoides*, abundant in these same formations, but also some shells which, like *Fulgur carica* and *F. canaliculatus*, *Calyptræa costata*, *Venus mercenaria*, *Modiola glandula*, and *Pecten Magellanicus*, are recent species, yet of forms now confined to the western side of the Atlantic—a fact implying that some traces of the beginning of the present geographical distribution of Mollusca date back to a period as remote as that of the Miocene strata."‡

* See Lyell's *Elements*, ch. xiv. and xv. † See Lyell, *op. cit.* p. 273. ‡ Lyell, *op. cit.* p. 275.

A distinguishing feature of the Miocene formations of Europe is the abundant fossil flora which they contain. In the Lower Molasse of Switzerland, for example, upwards of 500 species of plants have been found, including species of fig, palm, *Sequoia*, *Cinnamomum*, ferns, etc. The general character of the flora indicates a warm climate. Yet these plants have been found even in Greenland, where they occur abundantly, and of full size, in lat. 70°. Hence we are led to infer that the higher temperature was not characteristic of Europe only, but extended over the northern hemisphere.*

Foreign Localities.

For fuller information on the development of Miocene rocks abroad, the student may consult the Elementary Manual of Sir Charles Lyell, and the authorities cited by him. A mere reference to the subject is subjoined here.

Belgium and France.—The Bolderburg beds, the Faluns of Touraine and Bordeaux, the Falunien supérieur of D'Orbigny, are classed by Lyell as Upper Miocene. In his Lower Miocene he places the Rupelian of Dumont, occurring near Antwerp, the Kleyn Spawen beds of Limburg, and the lacustrine strata with mammalia found in Auvergne in central France. Associated with the latter were the earliest beds of lava and volcanic breccias which began now to be poured forth in the districts of Auvergne† and Velay, and continued to break forth at intervals to later times.

Germany and Switzerland.—As Upper Miocene are included, by the same author, the strata of the Vienna basin, and the upper and middle Molasse of Switzerland, the former yielding an abundance of dicotyledonous vegetation, the latter a marine fauna. As Lower Miocene, the beds of the Mayence basin, and the Lower Molasse of Switzerland, which is chiefly of freshwater origin, and contains some enormous masses of conglomerate. Nothing is more calculated to strike the geological traveller on his first visit to Switzerland than the vast deposit of the "Molasse," occupying the central region between the Alps and the Jura. This is the country of the great lakes, extending from that of Geneva to that of Constance. The level of those two lakes is from 1100 to 1225 feet above the sea, that of the Brienzer Zee is nearly 1800, the other large lakes being of intermediate heights. The hills by which these lakes are environed have all the rugged and broken character of mountains, and rise into peaks of various altitudes, up to that of 6050 feet, which is the height of the Rigi Kulm. These hills, which, if they were not overshadowed by the still loftier Alps, would themselves be celebrated mountains, are composed from top to bottom of beds of sand and gravel, occasionally compacted into sandstone and conglomerate, of more recent origin than the newest beds of the Isle of Wight. Their thickness is equal to that of one of our Palæozoic groups,—the conglomerate, called Nagel-flue, forming all the upper part of the Rigi, being itself stated at 6000 feet thick.

Italy.—Part of the beds in the hill of Superga, near Turin, correspond in fossil contents with the Upper Miocene strata of Touraine and Bordeaux, while beneath them are others in which well-known Lower Miocene plants have been found.

India.—The Sewalik formations which compose the sub-Himalayan range of hills have yielded a great variety of fossil mammalia and reptiles, as well as freshwater shells. These are parallel with the Upper Miocene fauna of Europe.

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* See Heer's *Flora Tertiaria Helvetiæ*. Lyell, *op. cit.* chap. xv.

† The great volcanic mountains of the Cantal, and that of the Mont Dor in Auvergne, are of far earlier date, as may be surmised from the worn and eroded condition of their flanks, and the destruction of their central cones and craters, when compared with the perfect state of the volcanoes which are probably of Miocene age.

CHAPTER XL.

PLIOCENE PERIOD.

Of this period we again have representatives, though small ones, in the British Islands. These occur in Suffolk and Norfolk, where, spreading over the Lower Eocene formations, they overlap upon the Chalk. Their uppermost beds consist of an assemblage of sands and gravels, which are locally termed Crag. They have been divided into three groups, on account of the different assemblages of organic remains which they contain. Two of these are termed Older Pliocene; the third is classed as Newer Pliocene. They are subdivided as follows:—

	Feet.
3. Norwich Crag	20
2. Red Crag	50
1. Coralline Crag	30

1. **The Coralline* Crag** is composed chiefly of soft marly sands of a white colour, sometimes speckled with green, containing occasionally thin bands of flaggy limestone. It is generally about 20 feet, but sometimes as much as 50 feet in thickness. Near Ipswich it has been denuded, and the Red Crag is seen to lie in the hollows that have been eroded in it, which is the only direct evidence of the superposition of the Red Crag on the Coralline; otherwise they lie side by side, the Coralline Crag being confined to a strip of country twenty miles long by three or four wide, stretching through Ipswich from the Stour river to the Alde river. 350 species of marine mollusca have been found in this formation. Of these 110 appear to be extinct, or 31 per cent.†

Characteristic Fossils.

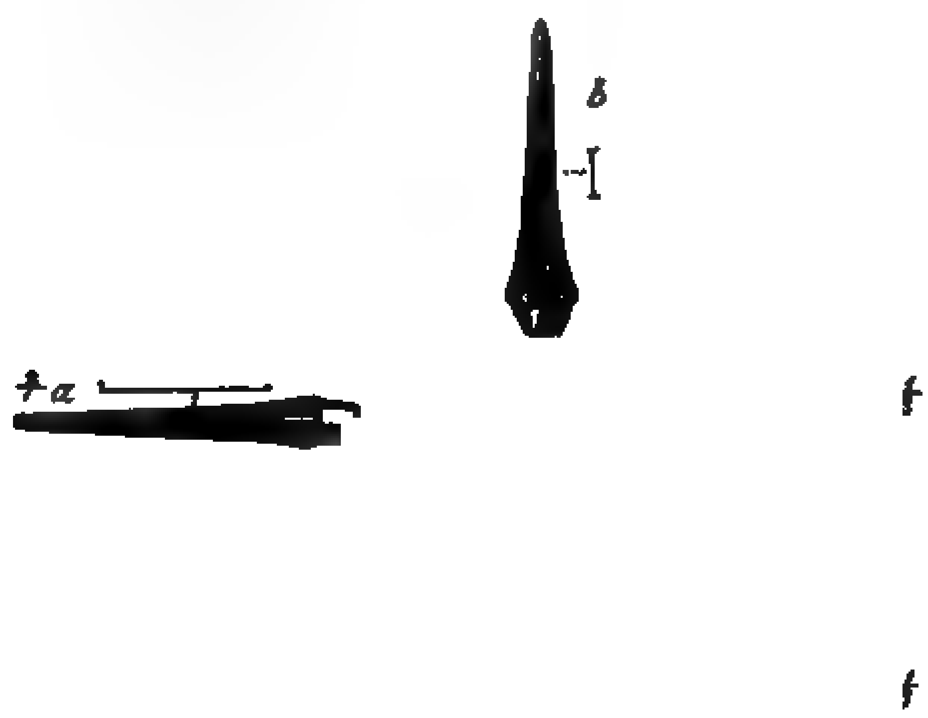
Foraminifera .	Operculina complanata.	
Actinozoa . .	Flabellum Woodii . . .	Br. Foss. Cor.
Polyzoa . . .	Cellepora cellulosa . . .	Busk's Crag. Pol.‡

* It appears that this term Coralline, although now settled by usage, was in reality a mistake, inasmuch as true Corals are rare in the Crag, and the coral-like bodies found abundantly in the "Coralline," but not entirely absent from the "Red" Crag, are not in reality *Actinozoa* but *Polyzoa*.—(*Pal. Soc.*, Edwards and Haime.)

† Searles Wood, in *Pal. Soc. Monograph.*

‡ Busk's "Polyzoa of the Crag," *Pal. Soc. Monograph.*

Polyzoa	Theonoa globosa	Busk's Crag. Pol.
	Fascicularia aurantium	Ly. Man. fig. 155.
Brachiopoda	Terebratula grandis (and Red Cr.)	Foss. gr. 46, *c*.
	Lingula Dumortieri	Ly. Man., fig. 160.
Conchifera	Astarte Omalii (and Red Cr.)	Foss. gr. 46, *d*.
	Cardita senilis (and Red Cr.)	*Ibid.* 46, *e*.
	Coralliophaga cyprinoides	Wood, Crag. Mol.*
	Cyprina rustica	Tab. View.
	Ostræa princeps (and Red Cr.)	Wood, Crag. Mol.
	Pecten Gerardi	Tab. View.
Gasteropoda	Pyrula reticulata	Ly. Man. fig. 156.
	Bullæa sculpta	Wood, Crag. Mol.
	Cassidaria bicatenata	Tab. View.
	Voluta Lamberti	Foss. gr. 46, *f*.
Echinodermata	Comatula Brownii	Forbes, Ter. Ech.
	Echinus Woodwardii	Foss. gr. 46, *a*.
	Temnechinus excavatus	*Ibid.* 46, *b*.
	Echinocyamus pusillus	*Ibid.* 47, *b*.



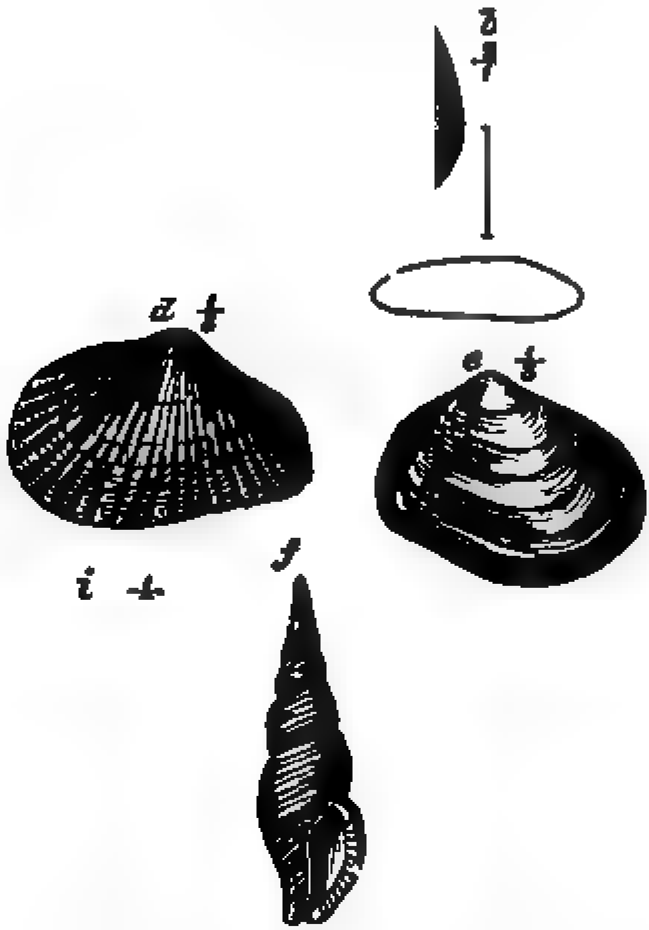
Fossil Group No. 46.

Coralline Crag Fossils.

a. Echinus Woodwardii.
b. Temnechinus excavatus.
c. Terebratula grandis.
d. Astarte Omalii.
e. Cardita senilis.
f. Voluta Lamberti.

* "The Mollusca of the Crag," by Mr. Searles Wood, *Pal. Soc. Monograph*.

2. **The Red Crag** consists of beds of red quartzose sands and gravel, with accumulations of rolled shells. It is very variable in character, sometimes regularly stratified, sometimes more confused.



Fossil Group No. 47.—Red Crag Fossils.

a. Balanophyllia calyculus.	d. Cardium angustatum.	g. Natica hemiclausa.
b. Echinocyamus pusillus.	e. Mactra constricta.	h. Purpura tetragona.
c. Astarte obliquata.	f. Columbella sulcata.	i. Nassa reticosa.

Like the Coralline or White Crag, it resembles the deposits which we may now suppose to be taking place in the shallow bed of the German Ocean. Of 256 species of marine shells found in it, 65, or 25 per cent, are extinct.

Characteristic Fossils.

Foraminifera	Polymorphina communis	(Living.)
Actinozoa	Balanophyllia calyculus	Foss. gr. 47, *a*.
Conchifera	Artemis lentiformis	Tab. View.
	Astarte obliquata	Foss. gr. 47, *c*.
	Cardium angustatum	*Ibid.* 47, *d*.
	Mactra constricta	*Ibid.* 47, *e*.
	Pecten plebeius	Tab. View.
	Pectunculus variabilis	*Ibid.*
	Nucula Cobboldiæ	Ly. Man. fig. 145.

Gasteropoda . .	Columbella sulcata	Foss. gr. 47, *f*.
	Cancellaria costellifera . . .	Tab. View.
	Cypræa Europæa	Ly. Man. fig. 153.
	Fusus antiquus	Tab. View.
	—— contrarius (Triphon antiquum)	*Ibid.*
	Nassa reticosa	Foss. gr. 47, *i*.
	Natica hemiclausa	*Ibid.* 47, *g*.
	Purpura tetragona	*Ibid.* 47, *h*.
	Scalaria Grœnlandica	(Living.)
	Voluta Lamberti	Ly. Man. fig. 157.
Mammalia . .	Balænodon emarginatus (ear-bones)	Tab. View.
	Felis pardoides	Owen, Foss. Mam.
	Mastodon Arvernensis (angustidens)	*Ibid.*
	Rhinoceros Schleiermacheri.	
	Tapirus priscus.	
	Cervus anoceros.	

There are many fossils common to the Coralline and Red Crags, some of which lived in both periods, but others may possibly have been washed as fossils from the Coralline into the Red Crag. There are also fossils common to the two Crags and to more recent deposits, and it is obviously likely that the still existing species found in either of the Crags will also be found in any or all subsequent deposits, either in the British area or elsewhere, according to their subsequent migrations. Of the living species that are found in the Red Crag but not in the Coralline or any earlier deposit, it is noteworthy that they have a rather more northern character than the fossils of the Coralline Crag have, many of them still inhabiting our own coasts. Others, however, with many of the living species of the Coralline Crag, are now only to be found in more southern seas.

3. Norwich or Mammaliferous or Fluvio-marine Crag.—There are in the neighbourhood of Norwich certain beds of sand, gravel, and loam, which go by the name of Crag, as well as the two older divisions of the Pliocene series just described. They have yielded a mingling of land and fresh-water shells, with a large proportion of marine species, together with bones of several extinct species of Mammalia. The land and fresh-water shells amount to 20 species, all still living, save possibly one species. The marine species number 124, of which about 18 per cent are extinct. There is a certain admixture of northern species in the molluscous fauna of the Norwich Crag, indicating the beginning of that severity of climate, which reached its climax later in what is known as the Glacial Period, when many Arctic species of shells lived abundantly in our seas, where they are now either extinct or exceedingly rare.

Characteristic Fossils.

Brachiopoda	Rhynchonella psittacea.
Conchifera	Nucula Cobboldiæ.
	Panopea Norvegica.

Conchifera	Tellina obliqua.
	Astarte borealis.
	Cardium edule.
	Cyprina Islandica.
	Pholas crispata.
Gasteropoda	Fusus antiquus.
	—— striatus.
	Littorina littorea.
	Natica helicoides.
	Turitella communis.
	Scalaria Grœnlandica.
Fish	Bones of several species.
Mammalia	Mastodon Arvernensis.
	Elephas meridionalis.
	Deer, extinct species.

Foreign Localities.

The student is again referred to the *Manual* of Sir Charles Lyell, who has collected a body of information on the Tertiary rocks of foreign countries.

Antwerp.—Some strata around Antwerp, and on the banks of the Scheldt below that city, contain 200 species of shells, of which two-thirds are the same as those of the Crag of Suffolk. More than half are living species, principally belonging to the Celtic, though some are Lusitanian (Mediterranean) species.*

Italy.—The sub-Apennines, or low hills intervening between the Apennines and the sea, on each side of Italy, are made of Tertiary strata, of which part are of Miocene, part of Pliocene, and part of a still more recent period. The beds of Asti and Parma, and the blue marl of Sienna, which near Parma is 2000 feet thick, over which are yellow sands and conglomerates formed on the shallowing of the sea, belong to this period, as do the Tertiary marine beds forming the base of the seven hills of Rome.

Sicily.—Strata of newer Pliocene age cover nearly the half of Sicily, and rise to a height of 3000 feet above the sea. Their upper calcareous division sometimes attains a thickness of 700 or 800 feet. Philippi states that out of 124 species of fossil shells from these deposits, 35 are extinct.†

S. Russia.—Sir R. I. Murchison and M. de Verneuil describe limestone and sands rising occasionally to the height of several hundred feet above the sea around the coasts of the Caspian and Aral Seas, and the north-western parts of the Black Sea, as belonging to this period. They call them the Aralo-Caspian formation. The fossils are partly fresh-water, partly marine.‡

* Lyell, *Manual*, p. 205. † Lyell, *op. cit.* p. 191. ‡ *Geology of Russia*, p. 279.

CHAPTER XLI.

IV. THE POST-TERTIARY, QUATERNARY, OR PLEISTOCENE PERIODS.

GLACIAL PERIOD.*

REFERENCE has been made in the foregoing chapter to the evidence furnished by the Crag of a gradual refrigeration of the climate of this part of Europe. That diminution of temperature continued during the next geological period, and it is chiefly the process of this change of climate, and the traces which it has left behind it, which will occupy us in the present chapter.

In the deposits now to be described all the shells belong to living species; in the older beds the mammalia are partly extinct, in the later beds all the fossils are of recent species.

The fragmentary and local character of so many of the late formations makes it, as we have seen, often difficult to ascertain their order of sequence and age. We are left to draw inferences as to relative antiquity from the proportion of extinct species of fossils in the different deposits, but this test may often be most fallacious, and should not be used independently of the physical evidence of former changes furnished by the varying character of the deposits themselves. In many cases no order of superposition can be determined, because the deposits whose relative antiquity we wish to ascertain, are not found in contact, but in separate, and perhaps distant, localities. We can only arrange them in such sequence as appears best to harmonise their respective histories, and to indicate the most probable order of geological change.

The deposits indicative of the passing of that great section of Post-Tertiary time, known as the Glacial Period, may be grouped as under, the order being as far as possible a chronological one, with the oldest at the bottom, though it cannot be asserted positively that some of the divisions may not have been really contemporaneous with others which are here placed beneath them.

Table of the Glacial Deposits of Britain.

7. Moraines of valley-glaciers.
6. Higher Raised-beaches.
5. Stratified Clays with Arctic shells (Clyde beds).

* Re-written by the Editor.

4. Erratic Blocks.
3. Kames or Eskers, and upper sandy and gravelly Drift.
2. Boulder Clay, with beds of sand and gravel, which in some places contain marine shells. The lower part of the Boulder Clay or Till is in Scotland unfossiliferous, rests on ice-worn rock-surfaces, and is regarded as of terrestrial origin.
1. Sands, gravels, etc., with plants and mammalian remains (Cromer Forest-bed).

These deposits will be described in the order of their relative antiquity, beginning with the oldest, although, as already remarked, it is not always possible satisfactorily to make out a chronological arrangement, so that the order here given may require subsequent modification.

1. Beds under the Boulder-Clay.—Underneath the boulder-clay, to be immediately described, there occur occasional deposits, which serve in some cases to indicate the nature and position of the surface of the land previous to those geological conditions under which the boulder-clay itself was formed. Such deposits necessarily vary much in character, and may belong to long-separated periods of time, though agreeing with each other in lying below the boulder-clay. The most interesting and best known of them is that which, under the name of the Cromer Forest-bed, extends for about forty miles along the beach of the Norfolk coast. It consists of the remains of an old forest, of which the tree-stumps still remain, with their roots in the former soil, and overspread with the decayed vegetation which has become a kind of lignite, wherein, besides seeds of land plants and fresh-water shells, the bones of about twenty species of terrestrial mammalia have been found. Of these only half now survive, the rest being extinct. Among them occur *Ursus Arvernensis*, *Rhinoceros Etruscus*, and *R. megarhinus*, *Elephas antiquus* and *E. meridionalis*, *Equus fossilis*, *Hippopotamus major*, together with the musk-ox, mole, Irish elk, stag, beaver, etc.*

In Scotland some beds of terrestrial origin have been found in Ayrshire, underlying the boulder-clay, and containing remains of fresh-water plants as well as of the mammoth.†

Ice-worn Aspect of Britain.—The general surface of a great part of the British Islands, excluding the centre and south of England, has a smoothed contour, which is now recognised as the work of land-ice. Hills, valleys, and knolls of rock have been ground down, and have received that characteristic flowing outline which ice, alone of all natural agencies, can produce. When, moreover, we strip off the superficial cover of detritus, and examine the surface of rock underneath, we find it covered with the well-known grooving and striation

* *Geology of Norfolk* (1864), by Rev. John Gunn; Boyd Dawkins, *Quart. Journ. Geol. Soc.*, xxv. 210.

† Bryce, *Quart. Journ. Geol. Soc.*, xxi. 217.

which are met with by the side of every modern glacier. These markings are not disposed at random, but run in more or less parallel lines. And when we examine them over the length and breadth of the country, we discover that they point away outward in every direction from the main masses of high ground, indicating that the ice which produced them covered the land in a deep continuous sheet, like that of Greenland, and that it moved outward and downward from the high grounds to the sea. So vast was the mass of ice that it swept over even considerable hills, smoothing and striating their sides and summits. To this period, according to Professor Ramsay, is to be attributed the general erosion of the present lake-basins of Britain.* Another feature of the surface-geology of the country dates from the same period—the widely distributed boulder-clay.†

2. **Boulder Clay or Till.**—This deposit is not at all likely to be confounded with any other. It consists of a mass of unstratified clay, with blocks and boulders of stone stuck in it promiscuously, the whole seeming to be the result of an irregular pell-mell carrying forward and deposition of the materials.

The colour and general composition of the mass vary according to the nature of the rocks from which it has been derived. Thus, in a region of dark carboniferous shales, the boulder-clay is leaden, grey, or black; in one of Old Red Sandstone it is red, and so on.‡

The stones in the clay range in size from mere grains of sand up to masses a yard or more in length. Wherever the rock of which they consist has been of a kind to receive and retain surface-markings, the stones are found to be covered with ruts and striæ, which run for the most part along the long axis of each stone. There can hardly be any doubt that these markings have been produced under a sheet of land-ice in the manner already described,§ and that the boulder-clay is thus the product of the grinding of vast masses of ice over the country. From the study of the composition of the stones in the boulder-clay, it is usually possible to tell from what quarter they have been carried, and hence to ascertain the direction in which the ancient ice-sheet moved. In this way, for example, we learn that in Scotland there was a general divergence of the great ice-mass outward from the main mass of the high grounds, so that in one district the movement was northerly, in another southerly, or eastwards or westwards. Additional evidence

* See *ante*, p. 460.

† On the General Glaciation of Britain, see Agassiz, *Proc. Geol. Soc.*, iii. 327; *Edin. New Phil. Journ.*, xxxiii. 217; Ramsay, *Quart. Journ. Geol. Soc.*, viii. xviii.; *The Old Glaciers of Wales*, 1859; *Physical Geography of Britain*, 1863; Chambers, *Edin. New Phil. Journ.*, liv. 229; Maclaren, *Edin. Phil. Journ.*, 1849; Jamieson, *Quart. Journ. Geol. Soc.*, vol. xviii.; Geikie "On Glacial Drift of Scotland," *Trans. Geol. Soc. Glasgow*, i. part ii., and *Scenery of Scotland*; Maxwell H. Close on "Glaciation of Ireland," *Journ. Geol. Soc. Dublin*, 1868.

‡ Geikie, *Trans. Geol. Soc. Glasgow*, i. part ii. p. 37.

§ See *ante*, p. 408.

of the former presence of land-ice, and of the direction in which it moved, is furnished by the smoothly-polished and striated surface of rock on which the boulder-clay is usually found to rest. Such worn surfaces are unequivocally the work of land-ice, like the *roches moutonnées* described in a previous chapter.* They are found all over the surface of Scotland, Ireland, the north of England, and Wales. So perfectly indeed are all, even the hardest rocks, rounded and smoothed, that the very universality of the process prevents its striking an eye not instructed in the nature of the phenomenon. The summits of the highest mountains, which either rose above the ancient ice-sheet, or which have been broken up by atmospheric waste since the glacial period, bristle with rough peaks and crags, but their lower slopes are all smooth and rounded, and this smoothing is continued down even below the level of the sea. In many cases precipitous faces of hard rock have been *undercut* into broad grooves and mouldings, of several inches in depth, and a foot or two in width, just as the precipices which glaciers now rub against are grooved. The surface of the rocks on the slopes and tops of the hills are traversed also by striæ, or scratches running in parallel lines, sometimes as faint as the lines of an engraving, but often deep enough for a thick pencil to lie in, or even deeper ruts or flutings, which would hold a human body. These characteristic surface features have been produced by the grinding of a thick mass of ice over the face of the country, while the boulder-clay itself represents the *grundmoräne*, or bottom-moraine of the same ice-mass.

There occur, however, such marked differences between the boulder-clay of distinct districts as to point probably to considerable diversities of origin. The description already given applies to the massive lower boulder-clay or till of Scotland and the north of England. But in parts of the Scottish till there occur intercalated local beds of sand, clay, and gravel, sometimes full of peaty vegetation, and with remains of the mammoth, etc. Such intercalations appear to indicate warmer periods, when the ice had, partially at least, retired from the face of the country, so as to allow vegetation and large mammals to cover it anew.†

We have still much to learn, however, regarding the flora and fauna of the land during the climax of the Ice age. It is easy to understand that, when the country, so far as it then rose above the sea, was covered with snow and ice, little trace need be looked for of the contemporary land-surfaces, or of the vegetation and the animals which then lived there. Still, some glimpses have already been obtained into this subject, and more may be expected as new sections of the boulder-clay are examined. Of the Mammalia characteristic of the Glacial Period, may be mentioned the Mammoth,

* See *ante*, pp. 408, 409.

† See Geikie, *Trans. Geol. Soc. Glasgow*, i. part ii. p. 53; Mahony, *Geol. Mag.*, vi. 390.

tichorhine Rhinoceros, Reindeer, Musk-sheep, *Bos primigenius*, *Bison priscus*, and *Cervus megaceros*.

Immense numbers of teeth and tusks of the mammoth are found in Siberia, and complete beds of them in Escholtz Bay, on the north coast of America. The whole carcass of the animal has actually been recovered from a frozen cliff in Siberia, and found to be coated with long coarse hair, forming a shaggy mane about the neck, underneath which was a woolly coat, evidently a defence against the severity of a cold climate, and showing that, unlike our modern elephants, the animal was not tropical but arctic. Its tusks are largely exported from Siberia to be used as ivory, and some found in England have been thus used. They were longer and more incurved than those of either of the existing elephants, some of the tusks measuring ten feet in length, while the transverse plates of the teeth were closer and narrower than in the Asiatic elephant, and very different therefore from the African, in which the plates of enamel form lozenges on the upper surface. At Escholtz Bay the cliffs are said to be either ice or coated with ice, and on the top of them, embedded in, and partly covered by, boggy and sandy soil, are numberless bones that have lost but little of their animal matter, hair being dug up with them, and the whole island having a charnel-house smell. The bones were those of *Elephas primigenius*, *Equus fossilis*, *Cervus alces* (moose deer) and *C. tarandus* (reindeer), *Ovibos* (musk-sheep), *Ovibos maximus* (a musk-sheep of greater size than any living one), *Bison latifrons* (Arctic fossil Bison), *Bison crassicornis* (heavy-horned bison), and other bovine animals.* A whole carcass of the *Rhinoceros tichorhinus* has been in like manner dug out of the frozen soil of Siberia, and is described by Pallas as covered with a woolly coat.

The *Cervus megaceros* or *Megaceros Hibernicus*, of which the remains have been not unfrequently found in Ireland, was not an elk, as it is often called, but a true deer, intermediate between the fallow-deer and the reindeer. It inhabited the same frozen plains with the extinct mammoth and the woolly rhinoceros, and with the still living reindeer and musk-sheep.

In Lancashire a threefold subdivision of the boulder-clay has been made into—1. Lower boulder-clay; 2. Middle sands and gravels; 3. Upper boulder-clay; and this arrangement has been found to hold good over a large area of the low land in the north-west of England, the middle subdivision sometimes yielding marine shells.† In Scotland no such subdivision has been found practicable, although there,

* Richardson's *Polar Voyages*, p. 296.

† See the *Memoirs of the Geological Survey*, explanatory of the Maps of Lancashire, etc. Much information regarding the boulder-clays of the East of England will be found in papers by Mr. Searles Wood jun., *Quart. Journ. Geol. Soc.*, vols. xxi. xxiii. xxiv.

too, there occur, in the middle and upper parts of the boulder-clay, numerous lenticular patches of sand, gravel, and clay, in which marine shells are occasionally, though rarely found. There is also a difference between these upper parts of the boulder-clay and the stiff lower till, already described. They are, on the whole, more loose and gravelly than the latter, contain a greater number of large boulders, show sometimes a rude stratification, indicate a longer transport of their component materials, and in the maritime tracts contain fragmentary marine shells. We may, with some probability, regard these clays as really a continuation of the stiff lower unfossiliferous clay, into which they certainly pass, and from which it is often quite impossible to distinguish them. They may have been formed by the grinding of the same ice-sheet over the land; but they will then indicate for us those portions of the great *grund-moräne*, which, instead of accumulating on or close to the land, were actually pushed by the advancing ice far out to sea, where they were more or less affected by marine currents, and sometimes received and preserved marine organisms.*

Between the upper or marine parts of the boulder-clay and the succeeding glacial deposits, we are not yet able to draw any satisfactory line of demarcation, or, at least, to speak very definitely of the geological changes by which the former were succeeded by the later formations.

3. Upper Sandy and Gravelly Drift; Kames and Eskers.—Over a great part of the British Islands the boulder-clay is covered by masses of sand and gravel, spread more or less irregularly over the surface, and rising to heights of more than 2000 feet in Wales. That these gravels are of marine origin may be inferred from their wide extent, and their position on the tops of ridges and watersheds, but the fact is rendered certain by the occasional occurrence in them of marine shells. On the hill called Moel Tryfaen, near the Menai Strait, fifty-seven species of mollusca, indicative of a colder climate than that of our present seas, have been met with in the sands and gravels of the drift of that region, at a height of 1300 feet above the sea.† In Cheshire and other adjacent districts marine shells have been traced up to the height of 1200 feet, and near Dublin they occur at a similar elevation.‡

* *Trans. Geol. Soc. Glasgow*, i. part ii. p. 99.

† See Trimmer, *Quart. Journ. Geol. Soc.*, vol. i. p. 331. Darbishire, *Manchester Phil. Soc. Proc.* iii. 177.

‡ See Harkness, *Geol. Mag.* 1869, p. 545. Since the last edition of this Manual was published, marine shells have been found by the Rev. Maxwell H. Close in sands and gravels at heights of 1000 and 1200 feet above the sea. Near Ballyedmunduff House (1000 feet), on the east side of Three Rock Mountain, he obtained *Cyprina Islandica*, *Turritella communis*, *Ostrea edulis*, *Venus striatula*, *Mactra stultorum* (?), *Mya truncata* (?), *Pecten* (small species): while near Calbeck Castle, on the west side of the same mountain, at a height of 1200 feet, he found *Cyprina Islandica*, *Mactra stultorum*, and *Venus casina* (?), along with chalk flints. —[MS. note furnished to the editor by Mr. Close.]

The marine drifts are well developed in Ireland, and a brief account of their occurrence there may be of interest to the student.*

"The centre of Ireland is chiefly a great plain of Carboniferous limestone, partly surrounded by several groups of lofty hills, composed of the older rocks, which rise from beneath the limestone. The hills to the south of this plain have every height, up to 3000 feet above the sea. Other hills, rising to heights of 800 or 1000 feet, are composed of Coal-measures lying on the limestone; these are surrounded by valleys which are branches of the limestone plain. The general level of the limestone plain is from 100 to 300 feet above the sea, only a few isolated hills of limestone in the interior of the country rising to as much as 500 or 600 feet.

"The low country is largely covered by a widely spread mass of Drift, consisting of dark sandy boulder-clay, with pebbles and blocks, and occasional beds of sand and gravel, sometimes very regularly stratified.† The great majority of the pebbles are rounded fragments of Carboniferous limestone, whence the deposit usually goes by the name of the Limestone-gravel. This deposit rests not only on the limestone, but sweeps up on to the flanks of all the hills, both those which are made of the lower Palæozoic rocks and those formed of the Coal-measures. In each case the limestone-gravel becomes largely mingled with detritus of the rocks of which the hills are made, and sometimes to such an extent that the local rocks assume a decided preponderance, and occasionally compose almost the whole of the deposit. The limestone-gravel is found in considerable abundance, however, and almost entirely composed of limestone pebbles, up to heights of 1200 feet on the granite mountains south of Dublin.‡ Chalk flints and pieces of hard Antrim chalk are found in it in the county of Dublin up to heights of 1200 feet, and at lower elevations along the whole eastern and southern coast of Ireland, at least as far as Ballycotton Bay, on the coast of Cork.

"A widely-spread mass of limestone-gravel, probably not less than 100 to 150 feet thick, forms the gently-swelling tract known as the Curragh of Kildare. The Coal-measure hills of Castlecomer coalfield have the limestone-gravel on their flanks, and also isolated patches of it, with blocks of limestone of a foot or more in diameter, in hollows on the top of the table-land at heights of as much as 700 and even

* This account of the Irish Drifts was published by the Author in the last edition. It is here retained, as giving a faithful description of the general character of these Drifts, though it does not profess to discriminate between such parts of the series as may be assigned to the marine conditions of the earlier or boulder-clay period, and those which are referable to the true upper sandy and gravelly drift of Great Britain.

† This seems to be the equivalent of the Scottish till, at least of its upper parts.

‡ See Explanation of Sheets 102 and 112, Geological Survey of Ireland, and paper by Mr. Kelly in *Journ. Geol. Soc. Dub.*, vol. vi.

1000 feet above the sea.* Other spaces at lower levels are quite free from any Drift, and it is doubtful in these cases whether the Drift was deposited in local patches or whether it once formed a general covering to the country, and has since been in part removed by denudation.

"Limestone-gravel, often with large blocks, which are picked out by the farmers and burnt for lime, is found high up on the northern flanks of all the hills of the south of Ireland, such as the Knockmealdon, the Galtees, the Slieve Bloom, the Keeper group, and the Slieve Bernagh and Slieve Boughta hills. In some cases the blocks are very large. Mr. O'Kelly mentions one of 25 ft. × 15 ft. × 5 on the Coal-measures near Killenaule.† Mr. Wynne gives a sketch of one 21 ft. × 9 ft. × 7½ resting on Silurian slate, at a height of 890 feet, near Moneygall.‡ Mr. Du Noyer § sketches that known as Cloghvorra, near Kenmare, which measures 26 ft. × 16 ft. × 15 ft., and rests upon Old Red Sandstone, but may be derived from the limestone in the valley below. Others are to be found in the valley under Caherconreagh, in the Dingle promontory.

"In an examination of Glenbarrow, on the north flank of the Slieve Bloom mountains, with Mr. O'Kelly, I was much struck with the facts to be observed respecting the Drift. These hills are composed of Lower Silurian rocks covered by Old Red Sandstone, and they slope gently down from heights of about 1600 feet to the limestone plain that stretches as far as the horizon around them to the west and north, and is only terminated towards the east by the Coal-measure hills of the Castlecomer coalfield, distant about ten miles. All the valleys of the Slieve Bloom seem once to have been completely filled with the great Drift deposit, rising with a gentle slope from the plain up nearly to the heads of the valleys. The present rivers have excavated channels for themselves either through this Drift, or between it and the solid rock, leaving the gently sloping surface of the Drift often most distinctly marked along the flanks of the more abruptly rising hills on each side of the valleys.|| In some cases the lower part of the drift is composed of the limestone-gravel, which is however very clayey, but contains both well-rounded pebbles and subangular blocks of limestone in great abundance. Over this come beds of fine sand and gravel, very regularly stratified, derived apparently from the local rocks, with comparatively little limestone. In some places this deposit entirely conceals

* See Explanation of Sheets 128, 137, and 146 of Geol. Surv. Ireland.

† Explanation 146. ‡ Explanation 135. § Explanation 184.

|| This appearance is general in Ireland in all the mountain valleys, and may be seen very characteristically in Glenismaule and the adjacent valleys near Dublin. The steeper hills, as they descend into the valleys, are met by gently sloping plateaux of Drift, forming inclined planes from the heads of the valleys towards their mouths, these inclined planes seeming once to have stretched continuously across the valleys, but being now deeply trenched by the ravines, at the bottom of which the present brooks run. They have no analogy with moraines, and in Glenismaule the Drift contains fragments of sea-shells near the mouth of the valley.

the limestone Drift below, except where the brooks cut deeply down into it. In other cases the lower part of the Drift is formed of the local rocks, and the limestone Drift occurs over it. One long escarpment of Drift in Glenbarrow, where the river is at a height of about 800 feet above the sea, and three or four miles from the limestone plain, shows cliffs of Drift 120 feet high, all regularly stratified, the upper fifty feet consisting of coarse Drift with limestone boulders, underneath which are beds, about 20 feet thick, of very fine laminated sand, and below that coarse rubbly Drift of sand and fragments, with angular blocks of Old Red Sandstone three feet in diameter. The rock below the Drift is Old Red Sandstone, which seems to have suffered considerable erosion and local decomposition before the limestone Drift was brought into the valley. The escarpment of the Drift is a nearly vertical cliff, being continually undermined by the river, which seems to have cut down along the sloping surface of the solid rock forming the opposite side of the valley deeper and deeper into the Drift, and to be now working slowly to clear its old valley of this recent deposit. I saw limestone blocks both in the Drift and loose in the river-bed, up to heights of 1260 feet in this glen; and Mr. O'Kelly assured me that he found small pieces of limestone and fragments of black chert, such as is found only in the limestone, even on the tops of the hills, above the level of any other Drift.

"The observed facts would agree well with the supposition that the whole country had been once covered with a thick deposit of Drift, which rose on the flanks of the hills to a much greater height than on the low ground, and to a still greater height, perhaps, in the valleys, which would catch a greater quantity of it. As the country rose above the sea, much of this loose superficial deposit would be removed from the outside slopes of the hills, and a good deal would be carried away from the plain, especially from off the summits of the lesser outlying eminences which rise from that plain. The part of the Drift which had filled the bottoms of the valleys would be chiefly left in them, and is only now in process of removal by the brooks which began to form as the ground rose again above the sea, and which have ever since run down these valleys.

"Sea-shells are found in the limestone-gravel in Glenismaule, near Dublin, and also in the Dargle valley, and in the valley west of the Sugar Loaf, and south of Enniskerry, County Wicklow, up at heights ranging from 500 or 600 up to 1000 and 1200 feet. They are found in greater abundance and much better preservation in the sands and marls which overlie (or form the upper part of) the limestone-gravel through the lower parts of the county of Wexford.* They are also to

* See Appendix to Edward Forbes's paper on Fauna and Flora of British Isles, *Mems. Geol. Surv.*, vol. i.

be found in the gravels of the more central parts of Ireland, as at Ballymore Eustace in Kildare, as I am informed by Mr. R. Callwell. Like the shells of the drift deposits in England, they are almost all of existing species, generally with a northern or Arctic or Boreal facies. But in the southern part of Wexford, Colonel Sir H. James formerly found fragments of shells (*Nucula Cobboldiæ, Fusus contrarius, Turritella incrassata*, and a *Mitra* allied to a Spanish species) which make it probable that the limit of the northern species ran thereabouts, and that the Boreal province here touched on the Lusitanian province (so to speak) of the Glacial period.

"That the superficial deposits now described were formed under the sea, notwithstanding the absence of sea-shells from the greater part of them, and especially their upper part, I have not the slightest doubt—a conclusion in accordance with those of Professor Ramsay regarding the Drift of North Wales."*

One of the most remarkable features of the upper gravelly and sandy Drifts is the way in which these deposits are often heaped into mounds and ridges, which sometimes run continuously for many miles over the surface of the country. Such ridges are known as Kames in Scotland, Eskers in Ireland, and Ösar in Sweden. These remarkable outlines are not due to mere denudation, but, as shown by the external structure of the mounds, have usually been produced at the same time as the mass of the sand and gravel was deposited.†

"There is a good deal of interest attached to the external form of some of the accumulations of Drift in Ireland. The deposit has evidently been in many places modified and shaped externally by the currents of the water, either at the time of its deposition or subsequently. The great bank of Drift near Killarney, and its removal round the Lower Lake, is one instance of this. There are, however, other conspicuous instances in the south of Ireland where the general form of the adjacent high lands has evidently some connection with the present external form of the Drift deposits in the low lands about them. Huge mounds of Drift are often accumulated in a bight of the hills, especially when there is a valley leading through the hills at the head of the bight. This is the case with the Drift mounds in the Kilmastullagh valley, between the Arra mountains and the extension of the Silvermines Hills towards O'Brien's Bridge; with the Drift mounds near Broadford, in the north-west bight of the Slieve Bernagh range; and with the Drift mounds near Roscrea, to the west of the valley between the south end of the Slieve Bloom hills, and the north extension of the Devil's Bit range. The great mounds of Drift near the town of

* *Quart. Journ. Geol. Soc.*, vol. viii. 371.

† The description of the Irish Eskers which follows was given by Mr. Jukes in the last edition.

Tipperary, and those of the Curragh of Kildare, have probably also a relation to the adjacent high land.

"These mounds in most cases probably received their form during their first accumulation, but sometimes the surface of the Drift seems to be one caused by subsequent erosion. In one conspicuous instance, two or three miles north of Parsonstown, which I visited in November 1861 with Mr. A. B. Wynne, a widely-spread expanse of deep horizontally stratified limestone-gravel appears to have been so far acted on by subsequent denudation as to have now an abruptly undulating surface, consisting of small mounds, ridges, and valleys, running in various directions over a space several miles in length, and one or two in breadth. One of these ridges, however, and the most conspicuous of them, formed a long Esker, or narrow gently undulating bank, some fifty feet above the surrounding flat country, and some miles in length. Such Eskers are very numerous in Ireland over all the low central plain. One is to be seen three or four miles to the west of Dublin, running from the banks of the Dodder, past the old castle of Tymon, by the Green Hills towards the valley of the Liffey. Others are marked on the Geological Survey maps near Stradbally, in the Queen's County, near Bagenalstown, near Maryborough, near Phillipstown, and in several other places.*

"The general form of an Esker is that of a long bank with steep sides, rising to a height of from 20 to 70 feet above the neighbouring ground. It is sometimes not more than a few yards wide on the top, but at other times spreads into wider mounds, and sometimes sends out spurs, or terminates in two or three undulating mounds. The broader parts of an Esker often have deep circular or oval hollows in them, 50 or 60 yards wide at the top, and 30 or 40 feet deep, without any outlet. Eskers often spring insensibly from a slope at the foot of a hill, and stretch with a gently undulating line for several miles across the flat country. The following examples will illustrate the general character of the Irish Eskers.

"The Maryborough Esker commences at the foot of the Coal-measure hills a little south of Maryborough, and runs off to the northward, unbroken for seven miles, to near Mount Mellick. It is then interrupted by a gap of a mile and a half, through which the little river Ownass flows, but it sets on again in the same line for another mile and a half, beyond which it coalesces with some irregular gravel-mounds. It stretches obliquely across the mouth of the wide open valley between the Coal-measure hills and the Slieve Bloom mountains. It does not, however, touch the latter, but sweeps in a parallel line round their north-east corner.†

* See Explanations of Sheets 100, 101, 102, 111, 128, 144, 147, 154, 155, etc.

† The country people about Maryborough affirm that this Esker stretches all across Ireland. Mr. Wynne was told that an Esker, near Borrisokane, a long way to the west of

"The Bagenalstown Esker commences on the limestone flat, but runs from that on to the granite, ascending a gently sloping ridge, which is 120 feet higher than the limestone plain, still preserving its form of a bank 40 feet high, until in about three miles it gradually spreads into low gravel-mounds, and becomes lost in the general mass of the drift which there covers the granite.*

"The Eskers are often opened for gravel-pits, as may be seen at the Green Hills near Dublin, and the arrangement of their materials is very curious. Irregular beds of large blocks, or of small pebbles, or of the finest sand, are arranged one over the other, generally with a rude attempt at conforming to the external slopes of the ridge, but not preserving for any distance either their thickness or inclination. These irregular beds seem to have been formed by the piling action of two opposing currents, or to have been heaped up in the eddy at the margin of currents running in different directions. Many of the Eskers were perhaps similar to "harbour-bars"† in their mode of formation, and may be directly related in this way to the valleys running into the neighbouring hills, which must, of course, have formed bays or harbours during some part of the last slow rising of the land above the sea. Others, however, especially those numerous ones which run in various directions all over the great central plain of Ireland, can only have been formed in the open sea by the action of different currents, as that sea became shallow in consequence of the elevation of its bed.

"The Eskers of the plains are often associated with the bogs, either running in lines between two large bogs, or partially or entirely surrounding flat spaces, which appear to have been converted into bogs in consequence of the Eskers having at one time retarded, and perhaps still retarding in some places, the drainage of the country, the superfluous water soaking through the porous base of the Esker instead of making a regular brook or river-channel for itself to run off by."

The Kames of Scotland resemble in all essential particulars the Eskers of Ireland. They are chiefly developed in the broad valley between the Highlands and the Southern Uplands, being especially re-

the Slieve Bloom mountains, was part of that near Maryborough. These stories may be taken as evidence of the similarity of the Eskers at different places, and their frequent occurrence in the centre of Ireland. Some of them seem certainly to be 15 or 20 miles in length, if we allow for occasional gaps or interruptions.

* Explanation of Sheets 147 and 157.

† An excellent example of an old harbour-bar may be seen at the Seven Churches, in County Wicklow. All the ruins are on a bank of Drift stretching across the main valley, and formed partly of the detritus from that valley, but chiefly, perhaps, from the other steeper and narrower valley, which must at one time have emptied its drainage into the old harbour, just about this point, and brought down the detritus, of which the tidal currents formed the bar.

markable in part of the valley of the Clyde to the east of Lanark, and also in that of the Forth near Falkirk.*

It is probable that the Eskers or Kames, and other modifications in the external form of the Drift deposits, were produced during the rise of the old sea-bed into dry land. It is also probable that the result of that elevation was a widely-spread plain, something like what Northern Siberia now is, which perhaps connected the British Islands with the Continent; and that the English Channel, and the Irish and North Seas, have been formed by the erosive action of the Atlantic eating into the lower and softer parts of that plain. On this plain, owing to the irregular forms in which the Drift was left, many lakes were formed, which have been filled up with lacustrine deposits, containing the bones of such animals as the great Irish deer (*Cervus megaceros*), and others.

4. Erratic Blocks.—Reference has been made to the large blocks of rock found in some of the boulder-clays and in the overlying gravelly Drift. There occur, however, in many parts of the British Islands, large, travelled stones (Erratic blocks, Erratics), lying on the surface, and not distinctly connected with any gravel or other deposit. They sometimes rest on rock, sometimes on boulder-clay, and sometimes on or in the upper sand and gravel Drift. They probably belong to the same great period of submergence to which the latter part of the Drift series is to be assigned, their transport having been effected on rafts of floating ice, by which they were borne over the submerged hills and valleys, sometimes to great distances from the ancient shores whence they were carried.

As the main mass of high ground in our islands lies to the north, the prevailing direction of transport of the blocks has been southward. Yet each isolated area of elevated land formed at the same time a centre of dispersion from which the stones were carried outwards in all directions, though more especially towards the south. The Highlands and Southern Uplands of Scotland, the mountains of the Lake country, and those of Wales, existed in this way as separate centres, from which the characteristic rocks of each district were dispersed. Thus blocks of greywacke, granite, and porphyrite, have been carried from the southern hills of Scotland far over the north of England. "Others, readily identifiable with rocks existing *in situ* in Cumberland and Westmoreland, may be traced in enormous abundance through Lancashire, Cheshire, and Shropshire, gradually dying away in Worcestershire and Gloucestershire. They may be found buried in the boulder-clay, as far as that extends, and also loose, scattered over the country, on the hill-tops or in the valleys, and spreading high up the flanks of the

* See Geikie, *Trans. Geol. Soc. Glasgow*, vol. i. part ii. p. 112. Milne Home on the *Estuary of the Forth*, 1871.

Welsh mountains on the one hand, and on the flanks of the Pennine chain which runs from Derbyshire into Scotland, on the other. Wasdale Crag, near Shap, is formed of a very peculiar porphyritic granite, with large crystals of red felspar; and blocks of this, together with many other kinds of rock, have been carried across the deep vale of Eden to the flanks of the Pennine chain, and even across it, especially over the pass of Stanemoor, which is 1440 feet above the sea, but is right opposite Wasdale Crag. Thence they have been distributed over the lower parts of Durham, and down the Vale of York, to the east coast of England.* Phillips mentions also a curious conglomerate, called 'brockran,' lying in the New Red or Permian rocks, in the bottom of the vale of Eden, blocks of which have also been lifted up and carried over Stanemoor." †

"Although the prevailing direction of transport has been southerly, examples occur both in the north and centre of England, of Erratics which have travelled in an opposite direction. Blocks of Cumberland rocks have been carried across the Solway into Scotland, according to Professor Sedgwick, and blocks of the Charnwood Forest rocks in Leicestershire may be seen a few miles to the north of the forest, although they are not so large, so numerous, or so far travelled, as those which may be found to the south of it.

"Many excellent illustrations of the transport of erratic blocks are furnished by the isolated group of mountains which rise upon or border the great plains of Ireland. Thus, the elevated tract of the Leinster granite sends off boulders in all directions except the north, but chiefly towards the south-east. In the Luggala Glen, running partly between the granite and the adjacent rocks, great blocks of granite are perched by hundreds on the rugged cliffs of mica-schist on the east side of the glen, or that facing the granite, and are strewed over all the country, whether on the hill-tops or in the valleys, between the granite and the sea. The largest of these blocks which I ever measured was an angular block, lying in a field a little below Annagolan Bridge, on the north side of the Vartry river, in the townland of Boleynass Upper. It measured 27 feet in length, about 15 in width, and rose 11 feet out of the ground. Its circumference was 82 feet. It rested on the Cambrian slates and grits, at a distance of about six miles from the nearest granite *in situ*, and on ground having a height of 620 feet above the sea. Between this block and the granite hills is the deep and rugged ravine of the Anamoe river, the high ridge which runs down from Douce Mountain on the east of that ravine, and the wide flat of the Vartry Valley below Roundwood. Many other cuboidal and angular blocks, measuring fifteen or twenty feet in the side, may

* Phillips' *Manual*, p. 422.

† The paragraphs within inverted commas are from the last edition.

be found on neighbouring hills, and the valleys are full of smaller rounded boulders. Blocks of granite, with a diameter of three or four feet, rest on the Cambrian rocks at the top of Bray Head, at a distance of five miles from the nearest granite *in situ*, and separated from it by several deep valleys (see Fig. 95).

"The granite which occupies, according to Sir R. Griffith's map, so large a portion of ground on the north side of Galway Bay, is easily recognisable, inasmuch as it contains hornblende instead of mica, and has large crystals of pinkish felspar, and is therefore porphyritic. Blocks of it may be found scattered over all the country to the south of the Bay, through Clare and Limerick, and the adjacent counties, as far south as Mallow, in the County Cork, a distance of about a hundred miles in a straight line. Many blocks, of two or three feet in diameter, may be found in the country about Nenagh, and on both flanks of the Slieve Bloom hills, up to heights of 1000 feet above the sea. Mr. O'Kelly met with one at a height of more than 1000 feet, about six miles N.W. of Mountrath, from which a large piece had been split by wedges, probably to make gate-posts, the part which remained measuring 10 ft. × 5 ft. × 3 ft. The Galway granite boulders, indeed, are numerous as far as the northern slopes of the Galtee mountains, but do not seem to have gone beyond the high grounds which stretch from those hills towards the west, nor, so far as I am aware, are they found in the neighbourhood of Killarney.*

"Mr. O'Kelly remarked to me that these granite boulders were chiefly on the surface, and not buried in the Drift"—an observation which applies equally well to the large travelled stones of Scotland.

"The Limestone gravel of the centre of Ireland seems to have been arrested by the east and west ranges of mountains and high land which stretch across the south of Ireland from Waterford to the coast of Kerry, as the Drift in the southern valleys among these high lands, and in the lower lands to the south of them, seems to be chiefly of local origin, though great mounds and local accumulations of it are to be found in some places."

5. Stratified Clays with Arctic Shells—(the Clyde beds).—In the estuaries of the Clyde and Forth the boulder-clay is overlain with certain stratified clays and sands, which are confined to the coast and the immediately adjacent inland. It is difficult to decide what is the exact place of these deposits in relation to the Sands and Gravels already described. The evidence at present obtained makes it probable that they are younger than the last-named parts of the Drift series. They chiefly consist of fine clays, sometimes laminated, sometimes showing only faint traces of stratification, and sometimes containing water-worn

* See the heading "Drift," in the Explanations of the Sheets of the Geological Survey Map of Ireland.

and ice-striated stones and boulders, either in single examples or scattered groups and bands. In these respects they closely resemble the stratified clays which occur in the boulder-clay, so closely indeed that they might be supposed to be in reality a part of that formation, were they not found resting on a rough denuded surface of boulder-clay. They are interesting as containing an abundant marine fauna, foraminifera, crustacea, mollusca, etc., with occasionally the bones of an arctic species of seal. The general character of the fossils indicates a more severe climate than that now prevailing in our seas. Several of the shells, such as *Pecten Islandicus*, *Tellina proxima*, and *Leda truncata*, are arctic species, and though the great majority of the fossils belong to species still found living around the British Islands, the characteristically northern forms occur proportionally more abundantly in these glacial deposits than they do in our present seas, while they often show in the fossil state a much larger size and greater thickness of shell than their living British descendants do.* These facts, taken in connection with the fossil evidence furnished by the Crag already referred to, afford an interesting and instructive example of change at once in the forms of life and the climate of the British region. They show how the gradual refrigeration of the climate during the deposition of the Crag reached its maximum a little later, during the formation of the Northern Drift or Glacial deposits.

Edward Forbes showed that species of mollusca which inhabited the British seas during the early part of the Pliocene Period, retreated to the south before the cold climate which afterwards spread gradually from the north, and that they then became inhabitants of the Mediterranean and adjacent parts of the Atlantic. These shells are found fossil in the newer Pliocene deposits of those regions, but many of them are not now found living there, having returned to our seas, as the cold influences retreated more and more to the north, and the severity of the climate became modified. Some of these species, however, still linger in certain localities in the south, a remarkable instance being the discovery by Mr. MacAndrew of the common Red Crag shell, *Fusus contrarius*, still living in Vigo Bay, a deep fjord on the coast of Spain, together with a complete colony of other Celtic species within the Lusitanian province.† Forbes's Celtic province seems to have come into existence between the Boreal and Lusitanian provinces, as a consequence of these changes of climate, an opening having been made between the two which has been subsequently occupied by that peculiar assemblage of species to which he gave the name of Celtic.

* For information regarding the Clyde beds, see the collected papers of Mr. Smith of Jordanhill, on "Post-Pliocene Geology," Glasgow, 1861; the paper by the Editor on the "Scottish Drift" already cited, and papers by Mr. Crosskey and others, in subsequent volumes of the *Transactions of the Geological Society of Glasgow*.

† Edward Forbes on *Nat. Hist. European Seas*, p. 109.

6. Higher Raised Beaches.—During the re-elevation of the land there were pauses when the upward movement either ceased altogether or became so slow that the sea had time to form beaches and cut terraces along the coast-line. Such beaches and terraces would thus remain to mark successive sea-margins, becoming necessarily fainter and more obliterated in proportion to their height, and consequently to their antiquity. These up-raised beaches consist of accumulations of sand and gravel, forming more or less continuous level shelves or terraces along the slopes of hills. Sometimes, instead of depositing these materials, the sea, aided probably by drift-ice, has cut a notch or terrace out of the Drift, or even out of solid rock. Such lines of ancient sea-margin are found at various intervals up to a height of 1200 feet or more above the sea. Those at the highest levels are of course the most ancient, and each of the succeeding lower terraces marks a stage in the gradual re-elevation of the country. They probably all belong to the glacial period, except those at a lower level than about forty feet above the sea. The latter date from times long after the final disappearance of glaciers in Britain.*

7. Traces of Valley-Glaciers.—After the re-elevation of the country the climate still continued severe enough to retain much snow and ice in the more hilly tracts. Each group of mountains thus gave rise to glaciers, which descended in some cases even to the sea-level when that level was about forty feet higher relatively to the land than it is now. In North Wales, the Lake District, the Southern Uplands, and the Highlands of Scotland, there were numerous glaciers which descended along the main valleys in all directions from each mass of high ground. So great indeed was the cold, that even small islands, where the snow-fields never could have been other than of very limited extent, nourished their independent glaciers. Beautiful illustrations are furnished by the islands of Arran, Mull, and Skye. The evidence for the existence of these valley-glaciers may be described under four aspects:—

1. *Ice-worn Rocks.*—The sides and bottoms of the valleys which have been occupied by the glaciers are well smoothed and striated, abounding in *roches moutonnées*, and the usual characteristic forms of ice-sculpture. These markings would not of course of themselves be enough to establish the fact of the former existence of valley-glaciers, as distinct from the great original ice-sheet; but their freshness and abundance, and often their comparative freedom from superficial detritus, when taken in connection with the following evidence, indicate that the markings were left by valley-glaciers.

2. The boulder-clays, sands, gravels, or other Drift of the earlier parts of the Glacier Period have been wholly or partially scoured out

* See R. Chambers's *Ancient Sea-Margins*, 1848, and *Tracings of the North of Europe*, 1850; Jamieson, *Quart. Journ. Geol. Soc.*, vol. xxi.

of the valleys, where these last glaciers existed.* This is well seen at the Pass of Llanberis and other valleys in North Wales, where the glaciers have ground and polished the sides and bottom of the glens, ploughing out the marine Drift which must once have filled these hollows, and which still rises on the mountain slopes of that region to a height of more then 2000 feet over the sea.

3. *Perched Blocks.*—On the ice-worn knobs and hummocks of rock in the valleys which have been traversed by the later glaciers, large fragments of rock have been left. These are precisely analogous to the *blocs perchés* or perched blocks of the Swiss valleys. They belong to rocks which are found in places higher up in the hills, and they have been carried down on the surface of the glaciers, and stranded in their present sites, as the ice which carried them melted away. It is clear that such poised stones could not have remained in their precarious position during the submergence and re-elevation of the land, but must have been laid down where we now find them, by glaciers which existed after the land had re-emerged.

4. *Moraines.*—But the most abundant, and perhaps convincing proof of the existence of these later glaciers is furnished by the numerous and well-preserved moraines which they have left behind them. Huge mounds of rubbish are found running in rudely curving horse-shoe-shaped lines across the valleys. Blocks of rock of all sizes, up to masses as large as a cottage, are strewn over the summits and sides of these ridges and hummocks. Between the mounds little hollows often enclose ponds or tarns, while sometimes the mass of moraine-stuff thrown across a valley has been enough to dam back the drainage and give rise to a lake.†

With the evidence furnished by the relics of the valley-glaciers, the records of the Glacial Period in Britain close. From the time when the land began to appear again from under the sea, the climate, though subject perhaps to alternations, was on the whole becoming milder. The amelioration advanced until the last snow-field and glacier finally disappeared. This change of temperature told importantly upon the fauna and flora of our area. The characteristically arctic forms—the woolly elephant and woolly rhinoceros, the musk-sheep and the reindeer—either died out altogether or retreated to more northern latitudes, where they could still enjoy their congenial climate. The Alpine plants which had covered the country were driven away from the lower grounds with the gradual increase of temperature, which, while proving unfavourable to them, permitted the flora of more southern districts to extend farther north. The plants of our mountain sides and

* See Ramsay, in his works already cited.

† For an account of the later glaciers of Britain see the works quoted in footnote on p. 705. Also J. D. Forbes, *Edin. New Phil. Journ.*, xl. 76; R. Chambers, *op. cit.*, New Series, ii. 194.

tops are thus the descendants, and slowly diminishing representatives, of the northern vegetation which formerly spread over the lower grounds of Britain.*

Characteristic Fossils of the Glacial Deposits.

Plants . . .	Desmidiæ, several species.
	Diatomaceæ, 31 species found in a fresh-water deposit in the boulder-clay at Crofthead, Renfrewshire.
	Mosses, as Hypnum tamariscum.
	Ranunculus aquatilis, Galium palustre, Pedicularis palustris, Scirpus lacustris, Potamogeton lucens.
	Twigs, leaves, etc., of birch, oak, hazel, Scotch fir, etc. The above fossils indicate terrestrial and fresh-water conditions, and they are found in the stratified beds in the lower till. In the marine glacial deposits Nullipora polymorpha occurs.
Amorphozoa . .	Clionia celata.
Foraminifera† .	Quinqueloculina seminulum.
	Lagena levis.
	Polystomella striato-punctata.
	Globigerina bulloides.
	Cornuspira foliacea.
Bryozoa . . .	Lepralia Peachii.
	Crisia eburnea.
	Hippothoa catenularia.
Echinodermata .	Echinus Dröbachiensis.
	Haploaster gracilis.
Cirrhipedia . .	Balanus porcatus.
	——— balanoides.
	——— crenatus.
Conchifera . .	Saxicava rugosa.
	——— Arctica.
	Mya truncata.
	Panopæa Norvegica.
	Thracia myopsis.
	Tellina calcarea (proxima).
	Cyprina Islandica.
	Astarte sulcata.
	——— compressa.
	——— borealis.
	Cardium fasciatum.
	Mytilus edulis.
	Nucula nucleus.
	Leda pygmea.
	—— pernula.
	Pecten Islandicus.
Gasteropoda . .	Littorina littorea.
	——— rudis.
	Rissoa parva.
	Buccinum Grœnlandicum.
	Natica affinis.
	Trophon clathratus.
	Fusus antiquus.

* See on this subject the classic essay of Edward Forbes, *Mem. Geol. Survey*, vol. i.

† See papers in *Trans. Geol. Soc. Glasgow*, by Messrs. Crosskey and Robertson.

Pisces . . .	Vertebræ of several species.
Mammalia . .	Cervus tarandus (reindeer).
	——— alces (?).
	Megaceros Hibernicus.
	Bos primigenius.
	Elephas primigenius.
	Rhinoceros tichorhinus.

Foreign Localities.

The Glacial Period appears to have left over the north of Europe and America traces of its passage similar to those of our own area already described.

Northern Europe.—The description of the glacial phenomena of the British Islands will generally serve also for those of Northern Europe. The surface of Scandinavia and Finland shows everywhere the flowing outlines and the systematic striation so characteristic of ice-action. The present glaciers of Norway are but the shrunk remnants of the vast ice-sheets which once covered the country, and extended southwards over what is now the Baltic. The plains of Germany are strewed with fragments of the rocks of Scandinavia, some of them as big as cottages. These have been carried by ice either on the surface of what must have been then a continental glacier, or on bergs which broke off from the seaward ends of that ice-sheet. This Northern Drift is limited by a singularly tortuous line, which runs from the Tcheskaian Gulf (east of the White Sea), south towards the Ural mountains, but is then deflected back, and undulates boldly through the centre of Russia, to the foot of the Carpathian mountains, marking probably the limit of the Northern Sea during the time when the blocks were being transported. Its farthest point south is about Cracow, latitude 50°, and it runs thence along the northern foot of the highlands of Bohemia and Saxony, and the Hartz mountains, to the plains of Holland about the Zuyder Zee, and thence across the south of England, up the valley of the Thames, to the mouth of the Severn, in the Bristol Channel.*

The Alps and Switzerland.—In the centre of Europe the mountains of Switzerland and the Tyrol have preserved some portions of the fresh snowfields of the Glacial Period; for, large as the existing glaciers are, they must once have been vastly more extensive, both in thickness and in length. This is proved by the ice-marks on the rocks traceable to heights far above the present reach of the ice; also by the abundant and sometimes enormous blocks of rock found stranded on the Jura mountains, and which have been borne from the different parts of the central Alps, each valley carrying blocks from the rocks near its source. These blocks are now recognised to have been transported, not by icebergs, but by the ancient glaciers, which extended across the middle lake district of Switzerland, over the soft accumulations of the Molasse, and abutted on the slopes of the Jura.

India.—From Dr. Hooker's Himalayan Journals, it appears that the glaciers of the Himalayan mountains were in like manner much more extensive formerly than they are now.

North America.—The glaciation of the northern portion of the American continent bears testimony, like that of Europe, to the southward movement of a vast mass of polar ice. The surface of the land has been smoothed and striated, and boulder-clays and other glacial deposits have been formed, down at least as far as latitude 39°.†

* See Murchison's *Russia and the Ural Mountains*.

† For information on the glacial phenomena of North America see Logan's *Geology of Canada;* Ramsay, *Quart. Journ. Geol. Soc.*, xv. p. 200; Bigsby, *op. cit.*, vii. p. 215; Hector, *op. cit.* xvii.; Agassiz, *Atlantic Monthly;* Dana's *Manual*, p. 536.

Cause of the Cold of the Glacial Period.

From the facts now adduced the student will be able to realise the nature of the evidence from which it is known that a cold or glacial climate prevailed over the northern hemisphere at a comparatively recent geological period. It has been reserved for this part of the Manual to offer a brief explanation of the physical cause which seems most probably to have produced that severity of temperature.

Various theories have been advanced to account for the remarkable climate of the Glacial Period. Some of these endeavour to explain the phenomenon by reference to terrestrial changes, such as the distribution of land and sea, it being assumed that elevation of land about the poles would cool the temperature of the globe, while elevation of land round the equator would tend to raise it. The universality of the change of temperature, however, the absence of all proof of any such enormous vicissitudes in physical geography as such theories demand, and the growing evidence in favour of the existence of still older glacial periods in earlier geological time, go to make it evident that no such local changes produced the cold climate, but that the origin of that climate must be assigned to some far more general and perhaps regularly recurring cause.*

An impression, therefore, has long prevailed that the cold of the Glacial Period was not due to mere terrestrial changes, but was in some way or other the result of cosmical causes. Setting aside the untenable suggestion that cold or hot climates could be produced by the passage of the earth through cool or warm regions of space, the agency which most readily suggests itself is change in the eccentricity of the earth's orbit. But the direct effect of a high state of eccentricity, as shown long ago by Sir John Herschel,† is to produce an excessively cold winter followed by an excessively hot summer on the hemisphere whose winter occurs in aphelion, and an equable condition of climate on the opposite hemisphere. It is therefore obvious that neither of these conditions will account for the cold of the glacial period. Besides, whatever may be the deficiency of heat resulting from the sun's greater distance during, say, the winter in aphelion, this is exactly compensated by the greater length of the season, so that both hemispheres receive exactly equal amounts of heat. Sir John Herschel even maintains that this principle almost neutralises the direct effects of eccentricity. "Were it not," he says, "for the compensation we have just described, the effect would be to exaggerate the difference of summer and winter in the southern hemisphere, and to moderate it in the northern; thus producing a more violent alternation of climate in the one hemisphere, and an approach to perpetual spring in the other.

* See Lyell's *Principles of Geology*.

† *Trans. Geol. Soc.*, vol. iii. p. 293 (Second Series).

As it is, however, no such inequality subsists, but an equal and impartial distribution of heat and light is accorded to both."* A similar opinion was afterwards expressed by Arago,† Humboldt,‡ and others. Hence it became a settled point among geologists that no such change of climate as that which occurred during the glacial period could be the result of change of eccentricity.

About eight years ago Mr. James Croll began to investigate this subject, and he has since developed his views, which have been steadily gaining acceptance. It occurred to him that although a high state of eccentricity could not *directly* produce a glacial condition of things, it might nevertheless do so *indirectly*, by bringing into operation physical agencies which would lead to such a result. The following is a brief statement of the way in which he supposes change of eccentricity to have operated.§

["With its eccentricity at the superior limit, and the winter occurring in the aphelion, the earth would be 8,641,876 miles farther from the sun during that season than at present. The reduction in the amount of heat received from the sun, owing to his increased distance, would, to a great extent, lower the winter temperature. In temperate regions the greater portion of the moisture of the air is at present precipitated in the form of rain, and the very small portion which falls as snow disappears in the course of a few weeks at most. But in the circumstances under consideration, the mean winter temperature would be lowered so much below the freezing-point that what now falls as rain during that season would then fall as snow. But this is not all; the winters would then not only be colder than now, but they would also be much longer. At present the winters are nearly eight days shorter than the summers; but with the eccentricity at its superior limit and the winter solstice in aphelion, the length of the winters would exceed that of the summers by no fewer than thirty-six days. The lowering of the temperature and the lengthening of the winter would both tend to the same effect—viz. to increase the amount of snow accumulated during the winter; for, other things being equal, the larger the snow-accumulating period the greater the accumulation.

"As regards the absolute amount of heat received, increase of the

* *Cabinet Cyclopedia*, § 315; *Outlines of Astronomy*, § 368.

† *Edin. New Phil. Journ.* for April 1834, p. 224.

‡ *Cosmos*, vol. iv. p. 459. Bohn's edition, 1852.

§ This abstract is enclosed within brackets, and has been kindly furnished to me by my friend Mr. Croll himself. It is partly taken from the 2d part of his paper on Ocean Currents, *Phil. Mag.* for 1870, with some additions and omissions. The following are the dates of some of his papers on this subject, arranged in the way best suited for being read:—*Philosophical Magazine* for May, August, November, 1868; February, March, October, 1870; October 1871; February 1867; June 1867 (Supplement); August 1864; September 1869.

sun's distance and lengthening of the winter are compensatory, but not so in regard to the amount of snow accumulated. The consequence of this state of things would be, that, at the commencement of the short summer, the ground would be covered with the winter's accumulation of snow. Again, the presence of so much snow would lower the summer temperature, and prevent, to a great extent, the melting of the snow.

"There are three separate ways whereby accumulated masses of snow and ice tend to lower the summer temperature—viz.

"*1st*, The snow and ice lower the temperature by means of direct radiation. No matter what the intensity of the sun's rays may be, the temperature of the snow and ice can never rise above 32°. Hence the presence of the snow and ice tends, by direct radiation, to lower the temperature of all surrounding bodies to 32°.

"In Greenland, a country covered with snow and ice, the pitch has been seen to melt on the side of a ship exposed to the direct rays of the sun, while, at the same time, the surrounding air was far below the freezing-point.* A similar experience has been recorded by travellers on the snow-fields of the Alps.† These results, surprising as they no doubt appear, are what we ought to expect under the circumstances. Perfectly dry air seems to be nearly incapable of absorbing radiant heat. The entire radiation passes through it almost without any sensible absorption. Consequently, the pitch on the side of the ship may be melted, or the bulb of the thermometer raised to a high temperature, by the direct rays of the sun, while the surrounding air remains intensely cold. The air is cooled by *contact* with the snow-covered ground, but is not heated by the radiation from the sun.

"When the air is humid and charged with aqueous vapour, a similar cooling effect also takes place, but in a slightly different way. Air charged with aqueous vapour is a good absorber of radiant heat, but it can only absorb those rays which agree with it in *period*. It so happens that rays from snow and ice are, of all others, those which it absorbs best. The humid air will absorb the total radiation from the snow and ice, but it will allow the greater part of, if not nearly all, the sun's rays to pass unabsorbed. But during the day, when the sun is shining, the radiation from the snow and ice to the air is negative—that is, the snow and ice cool the air by radiation. The result is, the air is cooled by radiation from the snow and ice (or rather, we should say, *to* the snow and ice) more rapidly than it is heated by the sun; and, as a consequence, in a country like Greenland, covered with an icy mantle, the temperature of the air, even during summer, never rises much above the freezing-point. Were it not for the ice, the summers of North Greenland, owing to the continuance of the sun above the horizon,

* Scoresby's *Arctic Regions*, vol. ii. p. 379. Daniell's *Meteorology*, vol. ii. p. 123.

† Tyndall, *On Heat*, article 364.

would be as warm as those of England; but, instead of this, the Greenland summers are colder than our winters. Cover India with an ice-sheet, and its summers would be colder than those of England.

"2*d*, Another cause of the cooling effect is, that the rays which fall on snow and ice are, to a considerable extent, reflected back into space. But those that are not reflected, but absorbed, do not raise the temperature, for they disappear in the mechanical work of melting the ice. No matter what the intensity of the sun's heat may be, the surface of the ground will remain permanently at 32°, so long as the snow and ice continue unmelted.

"3*d*, Snow and ice lower the temperature by chilling the air and condensing the vapour into thick fogs. The great strength of the sun's rays during summer, due to his nearness at that season, would, in the first place, tend to produce an increased amount of evaporation. But the presence of snow-clad mountains and an icy sea would chill the atmosphere and condense the vapour into thick fogs. The thick fogs and cloudy sky would effectually prevent the sun's rays from reaching the earth, and the consequence would be, that the snow would remain unmelted during the entire summer. In fact, we have this very condition of things exemplified in some of the islands of the Southern Ocean at the present day. Sandwich Land, which is in the same parallel of latitude as the north of Scotland, is covered with ice and snow the entire summer. And in the island of South Georgia, which is in the same parallel as the centre of England, the perpetual snow descends to the very sea-beach. This rigorous condition of climate chiefly results from the rays of the sun being intercepted by the dense fogs which envelope those regions during the entire summer; and the fogs again are due to the air being chilled by the presence of the snow-clad mountains, and the immense masses of floating ice which come from the antarctic seas. The reduction of the sun's heat and lengthening of the winter, which would take place when the eccentricity is near to its superior limit and the winter in aphelion, would in this country produce a state of things perhaps as bad as, if not worse than, that which at present exists in South Georgia and South Shetland.

"But there is one cause, above all others, which tended to produce the glacial climate—viz. the deflection of the Gulf-stream and other ocean currents. A high condition of eccentricity tends, we have seen, to produce an accumulation of snow and ice on the hemisphere whose winters occur in aphelion. The accumulation of snow in turn tends to lower the summer temperature, cut off the sun's rays, and retard the melting of the snow. In short, a state of glaciation is produced on that hemisphere, while exactly opposite effects take place on the other hemisphere, which has its winter in perihelion. There the shortness of the winters and the height of the temperature, owing to the sun's

nearness, tend to prevent the accumulation of snow. The general result is that the one hemisphere is cooled and the other heated. This state of things now brings into play the agencies which lead to the deflection of the Gulf-stream and other great ocean currents.

"Owing to the great difference between the temperature of the equator and the poles, there is a constant flow of air from the poles to the equator. It is to this that the trade-winds owe their existence. Now as the strength of these winds will, as a general rule, depend upon the difference of temperature that may exist between the equator and higher latitudes, it follows that the trades on the cold hemisphere will be stronger than those on the warm. When the polar and temperate regions of the one hemisphere are covered to a large extent with snow and ice, the air, as we have just seen, is kept almost at the freezing-point during both summer and winter. The trades on that hemisphere will of necessity be exceedingly powerful; while, on the other hemisphere, where there is comparatively little snow and ice, and the air is warm, the trades will, as a consequence, be weak. Suppose now the northern hemisphere to be the cold one. The north-east trade-winds of this hemisphere will far exceed in strength the south-east trade-winds of the southern hemisphere. The *median line* between the trades will consequently lie to a very considerable distance to the south of the equator. We have a good example of this at the present day. The difference of temperature between the two hemispheres at present is but trifling to what it would be in the case under consideration; yet we find that the south-east trades of the Atlantic blow with greater force than the north-east trades, and the result is that the south-east trades sometimes extend to 10° or 15° N. lat., whereas the north-east trades seldom blow south of the equator. The effect of the northern trades blowing across the equator to a great distance will be to impel the warm water of the tropics over into the Southern Ocean. But this is not all; not only would the median line of the trades be shifted southwards, but the great equatorial currents of the globe would also be shifted southwards.

"Let us now consider how this would affect the Gulf-stream. The South American continent is shaped somewhat in the form of a triangle, with one of its angular corners, called Cape St. Roque, pointing eastwards. The equatorial current of the Atlantic impinges against this corner; but as the greater portion of the current lies a little to the north of the corner, it flows westward into the Gulf of Mexico and forms the Gulf-stream. A considerable portion of the water, however, strikes the land to the south of the Cape, and is deflected along the shores of Brazil into the Southern Ocean, forming what is known as the Brazilian current.

"Now it is perfectly obvious that the shifting of the equatorial cur-

rent of the Atlantic only a few degrees to the south of its present position—a thing which would certainly take place under the conditions which we have been detailing—would turn the entire current into the Brazilian branch, and instead of flowing chiefly into the Gulf of Mexico, as at present, it would all flow into the Southern Ocean, and the Gulf-stream would consequently be stopped. The stoppage of the Gulf-stream, combined with all those causes which we have just been considering, would place Europe under a glacial condition, while, at the same time, the temperature of the Southern Ocean would, in consequence of the enormous quantity of warm water received, have its temperature (already high from other causes) raised enormously.

"And what holds true in regard to the currents of the Atlantic, holds also true, though perhaps not to the same extent, of the currents of the Pacific.

"The following will perhaps convey some idea of what would be the effect on climate were the Gulf-stream deflected into the Southern Ocean:—

"Taking the breadth of the Gulf-stream at twenty-five miles, its depth at 1000 feet, its mean velocity at four miles an hour, and the temperature of the water, when it leaves the Gulf, at 65°, and the return current at 40°—certainly a moderate estimate both as regards volume and temperature—it has been shown* that the quantity of heat conveyed into the Atlantic by this stream is equal to one-fourth of all the heat received from the sun by that ocean from the tropic of Cancer to the Arctic circle. Were the Atlantic deprived of a quantity of heat so enormous, what would be the effect on the climate of Europe? From principles explained at considerable length in the paper just quoted, it is proved that, were it not for the Gulf-stream and other currents, the mean temperature of London would be 40° lower than it is at present.

"But there is still another cause which must be noticed:—A strong undercurrent of air *from* the north implies an equally strong upper current *to* the north. Now, if the effect of the undercurrent would be to impel the warm water at the equator to the south, the effect of the upper current would be to carry the aqueous vapour formed at the equator to the north; the upper current, on reaching the snow and ice of temperate regions, would deposit its moisture in the form of snow. Hence it is probable that, notwithstanding the great cold of the glacial period, the quantity of snow falling in the northern regions would be enormous. This would be particularly the case during summer, when the earth would be in the perihelion and the heat at the equator great. The equator would be the furnace where evaporation would take place, and the snow and ice of temperate regions would act as a condenser.

* Croll, *Phil. Mag.* for February 1870.

["**Submergence of Land during Glacial Period.**—It follows from the above reasoning, that when one hemisphere is under glaciation, the other will be enjoying a warm and equable condition of climate. As the snow and ice accumulate in the one hemisphere they melt in the other. But owing to the precession of the equinoxes, the glacial conditions will be transferred from the one hemisphere to the other every ten or twelve thousand years. Consequently, the long glacial period must have consisted of a succession of cold and warm intervals.

"It is obvious that the transference of the ice from the one hemisphere to the other would displace the earth's centre of gravity, and thus, as a consequence, produce oscillations of sea-level. Suppose the quantity of ice at present in the Southern hemisphere would make a sheet 1000 feet thick, extending down to, say latitude 60°, which is by no means an extravagant supposition, how much would the transference of this mass from the Southern hemisphere to the Northern raise the level of the ocean in the Northern hemisphere? A considerable amount of discussion has arisen in regard to the method of determining this point. The method which I have adopted (which is similar to that of Adhemar, with the exception that I take into account the effect produced by the displaced water) gives about 80 feet as the extent of rise at the North Pole.* Mr. Heath's method gives a rise of 128 feet;† Archdeacon Pratt's method gives a still greater rise;‡ while Rev. O. Fisher makes the rise 409 feet."§]

Evidence of Glacial Conditions in Earlier Geological Periods.—If the cold of the glacial period was due indirectly to the varying states of eccentricity of the earth's orbit, the same cause must frequently have recurred during the past geological history of the planet. We ought accordingly to expect some traces of earlier glacial periods among the various geological formations. Before Mr. Croll pointed out from theory the antecedent probability of the occurrence of more ancient cold periods, Professor Ramsay had called attention to certain beds of breccia which, as already noticed, appeared to him to indicate the existence of ice-action in Britain during the Permian period. He subsequently noted similar evidence in the Old Red Sandstone, and suggested that some conglomerates and breccias in the north-west of England may have been formed under conditions similar to those which existed during the accumulation of the more recent boulder-clays.|| The more ancient the deposit the less likely are we

* *Reader* for 2d September 1865. *Phil. Mag.* for April 1866.

† *Phil. Mag.* for April 1866, p. 323.

‡ *Phil. Mag.* for March 1866, p. 172.

§ *Reader* for 10th February 1866.

|| See Ramsay, *Quart. Journ. Geol. Soc.*, xi. 185. See also Mr. Cumming's *History of the Isle of Man* (1848), where the possible glacial origin of some of the Old Red Conglomerates was first suggested.

to find these characteristic ice-striations preserved upon the included stones. Yet, from the instances cited by Mr. Ramsay, there seems good reason to believe in the existence of glacial action in Britain during some of the palæozoic periods. Mr. Godwin Austen has pointed to the occurrence of travelled boulders in the chalk of Croydon, and suggested their having been transported by drift-ice. It is possible, however, that these stray examples might have been entangled in the roots of trees, and carried out to sea with the drift-wood.* Again, in the Miocene rocks of the north of Italy, and in the Eocene series of Switzerland, large erratics are found, and are regarded as evidence that glaciers and icebergs existed in Europe during part of at least two of the Tertiary periods.†

* *Quart. Journ. Geol. Soc.*, xiv.

† See Lyell, *Principles*, i. chap. x., and authorities there cited.

CHAPTER XLII.

HUMAN PERIOD.*

In the deposits which succeed those of the Glacial Period we find the first traces of Man. Whether he lived in Britain while the cold was still intense enough to nourish glaciers among the mountains cannot yet be definitely settled. But rude works of art have been met with in situations suggestive of frozen rivers and great floods, and in conjunction with the remains of animals which lived during the Glacial Period, and which have long since been extinct.

In dealing with man as a fossil which has to furnish its quota of evidence towards the history of life upon the globe, we do not depend merely upon remains of his organism or framework, as in the case of the other members of the animal kingdom. He is specially a "tool-making animal," and his tools or other objects fashioned by him are as good evidence of his presence as his bones would be. Such objects, too, are usually much more numerous and more durable than his bones; hence they are far more likely to occur as fossils. And in actual fact it is chiefly from articles of human workmanship, and not from relics of the human skeleton, that the early history of man has to be compiled. The arrows and spear-heads with which he hunted or made war, his knives, clubs, stone-axes, chisels, needles, and such like, furnish the materials for that history. These various objects are found in many different situations, imbedded in ancient deposits, just as other animal remains are. They must be treated as *fossils*, and according to the relative antiquity of the deposits in which they occur must their chronological classification be determined.

The oldest works of art yet known to us are implements of stone—heads for clubs, axes, spears, flint knives, and other objects whose use can only be guessed at. A gradation can be traced from the rough rude character of those in the oldest deposits down to the neatly-trimmed and polished implements found in later formations. These last are succeeded by metal tools, first of bronze, then of iron, indicating the gradual advance in knowledge attained by the early races. A classification, based on this order of succession, has been proposed by the Danish antiquaries, and very generally adopted—viz. 1. The Stone-Age; 2. The Bronze-Age; 3. The Iron-Age. Further research, how-

* Re-written by the Editor.

ever, has shown that the so-called Stone-Age embraces a period of such great duration, that while man continued to use implements of stone, valleys were excavated, the general surface of a country was changed, climate altered, animals became extinct, and man himself advanced considerably in the dexterity with which he could fashion his tools. Hence the deposits in which the rude implements occur are termed *Palæolithic*, those containing the less uncouth are called *Neolithic*.* Such distinctions are no doubt to some extent arbitrary. We find, for instance, that stone implements continued to be used long after the introduction of metal tools, and thus that the "Stone-Age" was in some cases prolonged even to the "Iron-Age." Nevertheless these distinctions are found on the whole to agree well with the other evidence, palæontological and physical, as to the relative order of the deposits to which they are applied.

I. PALÆOLITHIC.—Under this title will be described the oldest series of deposits in which human remains have been found.† It is naturally impossible, however, in many cases, to say how far the various deposits thus grouped together are contemporaneous, or what is the true chronological order among them.

1. Cavern Deposits.—The formation of caverns and subterranean tunnels in limestone and other calcareous rocks, has been already explained.‡ These cavities have frequently served as receptacles for the bones of terrestrial animals, and have retained the remains in complete preservation. There are several ways in which the bones might have been introduced, different caves showing one or more of these modes of introduction. (*a*.) The cave was in some cases a den, into which wild beasts dragged the carcasses of their prey, and where they themselves retired to die. Such was the well-known cave of Kirkdale, in Yorkshire, from which the bones of about 300 hyænas were obtained, together with the dung of the same animals, and with the broken and gnawed bones of elephants, hippopotami, rhinoceroses, cave-bears, wolves, oxen, hares, etc. Another hyæna-den has been described by Mr. Boyd Dawkins as occurring at Wookey-Hole, near Wells. He extracted from it between 800 and 1000 bones of various carnivora, as hyæna, wolf, fox, and bear, of the mammoth, tichorhine rhinoceros, reindeer, *Bos primigenius*, *Cervus megaceros*, and horse. Every one of the bones, including even the teeth, bore marks of having been gnawed. In the same cave human implements of flint and burnt bones were found, indicating that man was a contemporary of these animals.§ (*b*.) In other cases the caverns communicated with the surface of the

* Terms proposed by Sir John Lubbock in his *Prehistoric Times*.

† Including, of course, deposits which are strictly continuous with or representative of those containing human remains, although they may not themselves have yet yielded any traces of man.

‡ *Ante*, pp. 393, 394.

§ Boyd Dawkins, *Quart. Journ. Geol. Soc.*, xviii. xix.

country, owing to the occasional falling in of the roof, and animals have thus tumbled into the subterranean passages and left their remains there. (*c.*) But perhaps the most common mode of entombment was by underground streams. It has been already mentioned how the gradual solution of calcareous rocks under ground gives rise to the formation of channels in which rivers are sometimes engulphed.* The rivers have in such instances swept mud, sand, gravel, and the remains of animals, into the winding passages and chambers, and left them there as a deposit on the floor. Afterwards, when the rivers, by some other change, no longer flowed through these passages, or did so only now and then in floods, stalactites began to form from the roofs, and the drop of water on the floor gave rise to a layer of hard stalagmite, which accumulated over the bone-bearing earth or loam left by the river or flood. If the growth of the stalagmite were interrupted by occasional floods carrying new loads of earthy materials, these would form layers in the interrupted deposit of stalagmite.

That man was a contemporary of the animals whose bones are now found in these cavern deposits, is shown unequivocally, by the occurrence of flint knives and flakes imbedded along with the remains of these animals in the loam or earth of the caves, and covered with an undisturbed flow of stalagmite. The antiquity of the deposits is shown partly by the wide difference between the fauna which they contain and that of the present time, many of the animals being now quite extinct, and partly by the proofs of great changes in the physical geography of the country having taken place since the time when these caverns could have been reached by any flood.†

From the cave-deposits of England upwards of forty species of mammalia have been recovered. Among these may be mentioned man (as shown by worked flints), bear, fox, wolf, cave-hyæna, cave-lion, Irish elk, reindeer, wild bull or urus, bison, hippopotamus, wild boar, horse, rhinoceros, and mammoth.‡

2. Loess or ancient flood-deposits of the Rhine and other rivers.—When a river is in flood and turbid with sediment, it deposits a film of mud over those flat spaces where its current is slowest. The broad alluvial tracts on each side of the stream thus receive from time to time additions to their surface, the uniform flatness of which is at the same time preserved. During the later stages of the Glacial Period, or the earlier stages of the period which succeeded it, the melting of the snow and ice in summer, or a copious rainfall, or both causes com-

* *Ante*, p. 394.

† See the evidence on this subject collected by Sir C. Lyell in his work on the *Antiquity of Man*; also the Reports of the Committee for Exploring Kent's Cavern.—*Brit. Assoc. Rep.* The evidence for the antiquity of the human race is farther treated of a few pages farther on.

‡ See Boyd Dawkins on British Postglacial Mammals, *Quart. Journ. Geol. Soc.*, xxv. 194.

bined, swelled the rivers of Central and Northern Europe to a size much greater than that which they have since attained. Abundantly charged with mud, their waters rose high above their existing channels, and deposited on either side a thick deposit of flood-loam, or, as it is called in Germany, loess. The loess of the Rhine is in some places several hundred feet in thickness,—a pale yellow calcareous loam, for the most part unstratified, and containing land and fresh-water shells. Dr. Ami Boué found human bones under 70 or 80 feet of loess at Lahr, opposite Strasburg.

It is probable that in the case of the Rhine, Danube, and other large rivers rising in old glacier districts, the loess was really glacial mud. Professor Suess, indeed, informed the Editor that he had found striated pieces of Alpine limestone in the loess of the Danube at Vienna. But in other regions where no glacier can have supplied the abundance either of water or of mud, these may perhaps be attributed to a former more copious rainfall. It has been proposed, indeed, to regard the Glacial Period as having been followed by a Rain Period. In the valley of the Thames, for instance, the ancient flood-loam, or "brick-earth" as it is called, rises high above the present bed of the river, and similar brick-earths are found on slopes, and along their base, in places suggestive rather of rain-action on the general surface of the country than of the work of any stream. In the brick-earths of the south-east of England, remains of extinct mammalia, with works of human fabrication, are found. These will be described along with those of the other river deposits.

3. Ancient or Higher Valley Gravels.—As a river winds from side to side in its valley, it spreads out an alluvial deposit of sand, gravel, and silt, which extends as a flat tract down the valley, with the river meandering through it. By degrees the river, which is always deepening its channel, cuts through its own alluvia, and leaves fragments or strips of them on either side. In this way a succession of terraces is formed, the oldest being those which rise highest above the stream. These terraces of sand and gravel represent former ordinary levels of the river. They are sometimes covered with a coating of brick-earth or loess, showing the extent of former floods, by which mud was spread over the plain.

In the older gravels of the north-west of France, and of the south-east of England, remains of extinct mammalia, such as mammoth, tichorhine rhinoceros, and hippopotamus, are of frequent occurrence, and with them are sometimes associated characteristic stone-implements fashioned by human hands.*

For many years statements had been made as to the occurrence of

* The succeeding paragraphs, descriptive of the discovery of flint implements in the older valley gravels, are by Mr. Jukes, and appeared in the last edition of this work.

human remains in caves and other places associated with the remains of extinct animals; and also that skeletons of the megaceros in Ireland, and of the mastodon in America, had been found bearing the marks of wounds inflicted by human weapons. There was, however, too much doubt about most of these cases for geologists to accept them as conclusive evidence in favour of the contemporaneity of a race of men with the older extinct animals.* Man digs, and may therefore have dug up fossil bones, or buried those of his own race; if holes in bones were really the result of wounds received during life, they may have been made by horned animals in fight, or by hard stakes while the living animals were penetrating thickets, or by other accidents. The human skeleton found fossil in the Island of Guadaloupe, and now preserved in the British Museum, is enclosed in a coral rock that may be of quite recent origin, since similar rock is formed now in the banks on coral reefs, or wherever calcareous grains are heaped upon coasts.

Discoveries have, however, been made within the last ten or twelve years, which have brought the results of human workmanship within the scope of the same kind of evidence as that on which the geologist relies in all his other deductions, and which clearly proves the workmen to have been contemporaneous with the Mammoth and other extinct animals, and that they lived at a time when the physical geography of Northern France and Southern England at least was rather different from what it is now. The earlier of these discoveries are excellently described by Mr. Prestwich,† and by Mr. J. Evans,‡ from whose papers the following account is abstracted.

In 1841 M. Boucher de Perthes of Abbeville found the first flint implement in the old valley-gravels, or so-called "Drift" of that neighbourhood, and published an account of his discoveries in 1847 and 1857; but it was not till 1859 that his work attracted the notice of geologists in general; and the French localities were visited by Messrs. Prestwich and Evans, from whose reports they were afterwards examined by Sir C. Lyell and by MM. Desnoyers and Hebert, and other most competent and trustworthy observers.

The river Somme now, on approaching the sea, winds through a

* The human skulls and bones described by Dr. Schmerling of Liege, in 1833, as found mingled with bones of many extinct animals, in a cave 200 feet above the Meuse, and as being in the same state as to fracture, colour, and condition, with the other bones, was justly considered a strong case in favour of the human and animal bones having been deposited contemporaneously by natural causes. The flint implements found by the Rev. Mr. M'Enery, Roman Catholic clergyman of Torquay (whose name all geologists were familiar with thirty years ago), in the cave called Kent's Hole, seems to have been another good case in proof. Dr. Falconer found implements associated with bones of extinct animals in a cave near Palermo in Sicily. MM. Lund and Claussen, in like manner, found human remains associated with those of extinct animals in the caves of Brazil, under circumstances which satisfied them of their contemporaneous existence.

† *Philosophical Transactions*, 1860, Part ii. ‡ *Archæologia*, vol. xxxviii.

valley about a mile in width, the bottom of that valley having alluvial flats of silt and peat; and the Chalk hills on each side of it rising gently up to heights of 200 to 400 feet above the sea, hills of 500 or 600 feet being only met with in the interior of the country. Abbeville and Amiens are both on this river, the first at fourteen, and the latter at forty-one miles from the sea, the mean level of the river being 60 feet at Amiens and 18 feet at Abbeville above the mean level of the side at St. Valery, at the mouth of the river. The Chalk hills are covered here and there with sands and gravels, both on the higher grounds and on the slopes, down to the river valley, where these deposits pass under the silt and peat of the alluvial flats.* The sands and gravels, or "Drift" as they were formerly called, are in some places 20 or 30 feet thick, resting on an uneven eroded surface of Chalk, and lying often in regular layers over considerable areas, but, like all such deposits, variable in the thickness and constitution of their beds, when

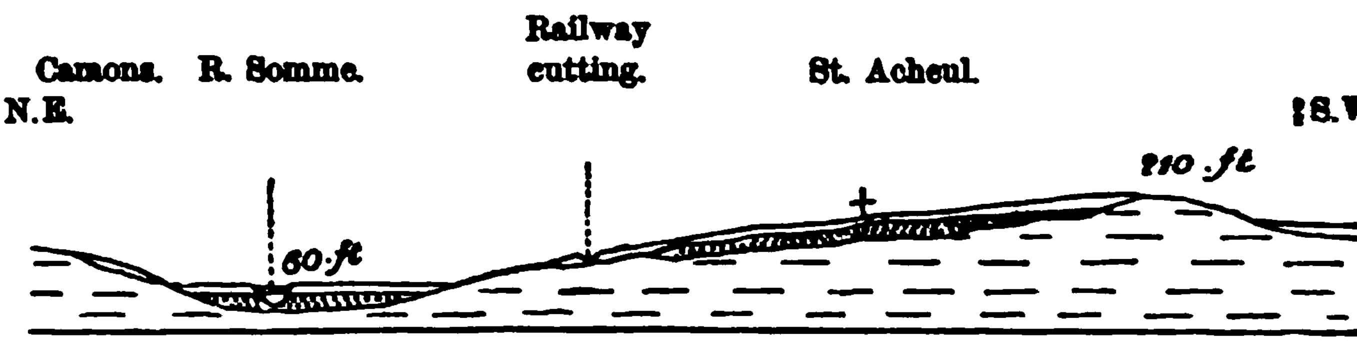


Fig. 166.

Section across Valley of Somme, near Amiens, reduced from Mr. Prestwich's section (*Phil. Trans.*)—Horizontal distance about 2 miles.

The lower part of this section is in chalk, represented by the horizontal strokes. The dotted portion represents the "drift," in which flint implements are found associated with the remains of extinct mammalia, and with recent land and fresh-water shells, and occasionally some marine shells. The undotted beds above that, and on the slope of the chalk at Camons, and in the valley south-west of the hill marked 210 feet, are the brick-earth. The upper undotted part on the flats of the Somme is silt and peat.

places a mile or two apart are compared with each other. Marine shells are found in them at some places, but at others land and fresh-water shells, of the same species for the most part as now inhabit the country, are found much more abundantly; teeth and tusks of the Mammoth, remains of the woolly Rhinoceros, and other extinct animals, also occur, and likewise a number of flints, which have obviously been worked into parts of weapons or implements by the hands of man.

The flint implements and extinct animal remains are found chiefly in the lower parts of the deposit, often under more than 20 feet of undisturbed stratified sand and gravel, and evidently deposited in the

* The term "Drift," used in the earlier papers on this subject, is apt to lead to confusion with the very different glacial drifts already described. It is now generally disused in favour of "valley-gravels," "ancient river-gravels," "high-level gravels," or some equivalent expression.

water in which these strata were laid down. They occur both near Abbeville and Amiens, at various heights, up to 90 feet or thereabouts, above the river, often beneath ground which is the highest in the immediate neighbourhood, having gentle slopes from it in all directions. It is therefore impossible with the present outline of the country, and the present depth of the river valley, and relative levels of land and sea, that any fresh-water lake or river could have existed over the spots, and yet the sands and gravels have evidently been deposited beneath fresh water.

The following is a section of one of the gravel-pits at St. Acheul near Amiens, where the general level of the ground is 149 feet above the sea, and 89 * feet above the Somme. This ground slopes gently to the N.E. for about a quarter of a mile, as far as the railway cutting, and then more steeply to the flats of the river. To the south of St. Acheul it is not commanded by any higher ground, since there is a hollow between it and the foot of the hills to the southward.—(See Fig. 166.)

	Ft.	In.
4. Surface soil	0	8
3. Brown loam in four beds, some of them slightly calcareous, others not so; a few naturally formed fragments of flint in some places; no organic remains or flint implements. This is the Brick-earth	12	2
2. White sand and marl, with a few large subangular flints or blocks of sandstone, etc.—(*Land and fresh-water shells common; some Mammalian remains; flint implements*)	4	10
1. Coarse subangular flint gravel in a base of white sand, with whole and broken flints, pieces of Tertiary sandstone, etc., and Tertiary and Chalk rolled fossils, subordinate seams of sand sometimes level, sometimes contorted, *Mammalian* remains, and *flint implements* dispersed throughout, but chiefly in the lower parts. *Shells*, mostly in fragments (*Helix*, *Limnea*, *Pisidium*, *Pupa*), in some of the sand seams	5	0
	22	8

The flint implements are found in some pits in considerable abundance, in others rarely; while in others they have never been found. Mr. Prestwich believes these fresh-water deposits to be of the same age and character as the Loess and Lehm of the Rhine valley.

Similar flint implements have also been found near the village of Hoxne in Suffolk, in some old brick pits. They were described by Mr. J. Frere, in a letter read before the Society of Antiquaries in 1797.† Here they were found in clay containing fresh-water shells, and having some layers of flint gravel, the whole forming a lacustrine deposit in a

* These are measurements accurately levelled by civil engineers.

† See papers by Mr. Prestwich and Mr. Evans, already quoted.

hollow of the Boulder Clay, which caps, or rather indeed forms the bulk of, all the hills around. This fresh-water deposit reaches within 6 or 8 feet of the summit of the hill on the slope of which it rests, at a height of 42 feet above the adjacent brook, 53 above the neighbouring river Waveney, and 112 above the sea. No ground more than a few feet higher exists for some miles around, and its position is such that "no existing drainage, nor any possible with this configuration of the surface, could have formed these clay and gravel beds at the relative level they now occupy." * The shells prove them to have been formed in a small lake or mere.

In May 1861, Mr. Prestwich read to the Geological Society of London a paper giving accounts of more recent discoveries of flint implements, with remains of extinct animals, near Bury St. Edmunds in Suffolk, near Herne Bay, and at Swale Cliff near Whitstable in Kent, near Bedford, and in Surrey and Hertfordshire, and calls attention to many other places at which they will probably be found when searched for. Since the date of his paper they have been found at many different localities in the south and south-east of England.

Nobody could see a tray full of these flint implements, and retain any doubt that they had been fashioned by human hands. Some of them are like rude arrow or spear heads, while others seem as if intended for digging or grubbing up roots, being chipped to a strong rather curved point at one end, while the natural undulating surface of the flint is retained at the other, the flint having been apparently chosen on account of its natural indentations at that end fitting to the shape of the hand, and giving a good grasp to the fingers. The unchipped parts have sometimes the natural white coating which is commonly seen on weathered flints, while the chipped parts have the dark colour of the interior. But most of the implements are of a brown hue (due to iron-stain), which passes on the one hand into black, and on the other into a tawny yellow.

There can then be no longer any dispute that man not only existed on the earth generally, but even inhabited these countries, before the extinction of the large mammalia already mentioned. What race of men it was that had to defend themselves with rude flint weapons against the great bears, lions, and hyænas, and preyed with them on the old reindeer, and other cervine and bovine or pachydermatous and proboscidean animals, and how many thousand years have elapsed since then, we are left to conjecture. Any one who has read carefully the preceding pages can judge for himself as to the time requisite for the animals to have become extinct, and for the alteration in the levels and the minor features of the surface of the ground to have been produced.

* Prestwich.

The climate may have then been more excessive than now, but not perhaps more so than that of Newfoundland at the present day, which is in the same latitude as the northern part of France, and is still inhabited by reindeer and bears, and even invaded occasionally by the Polar bear landing from an ice-floe, and which a century ago was inhabited by a race of Red Indians who lived chiefly on the reindeer, and the last of whom have either perished or fled to Labrador within the last forty years.

*Mammalia of British Palæolithic Deposits.**

	Cave Deposits.	River Deposits.
Homo	*	*
Rhinolophus ferrum-equinum	*	—
Vespertilio noctula	?	—
Sorex vulgaris	*	—
Ursus arctos	*	?
—— spelæus	*	*
—— ferox	*	*
Gulo luscus	*	—
Meles taxus	*	—
Mustela erminea	*	*
—— putorius	*	—
—— martes	*	—
Lutra vulgaris	*	*
Canis vulpes	*	*
—— lupus	*	*
Hyæna spelæa	*	*
Felis catus	*	—
—— (antiquus) pardus	*	—
—— leo (var. spelæus)	*	*
—— lynx	*	—
Machairodus latidens	*	—
Alces malchis	*	—
Cervus megaceros	*	*
—— tarandus	*	*
—— capreolus	*	*
—— elaphus	*	*
Ovibos moschatus	—	*
Bos primigenius	*	*
Bison priscus	*	*
Hippopotamus major	*	*
Sus scrofa	*	*
Equus caballus	*	*
Rhinoceros megarhinus	?	?
—— leptorhinus	*	*
—— tichorhinus	*	*
Elephas antiquus	*	*
—— primigenius	*	*
Lemmus, sp.	*	*
Lepus cuniculus	*	—

* This list is taken from the paper by Mr. Boyd Dawkins, *Quart. Journ. Geol. Soc.* (1869), xxv. 192.

	Cave Deposits.	River Deposits.
Lepus timidus	*	*
Lagomys spelæus	*	—
Spermophylus erythrogenoides	?	—
Arvicola pratensis	*	—
——— agrestis	*	—
——— amphibius	*	—
Castor fiber	*	?
Mus musculus	*	*

II. NEOLITHIC.—Under this division may be grouped those deposits in which are found human implements of stone, such as polished celts and other articles, indicating a considerable advance in civilisation. It is here that the geologist and archæologist begin to find common ground for research, each aiding and supplementing the work of the other.

Lake Dwellings.—In Switzerland, during a low state of the water, many traces of ancient dwellings have been found along the margin of some of the lakes. These dwellings were formed on piles of wood driven into the soft mud of the bottom. They appear to have been in use during many centuries. At some of them hatchets, knives, and other instruments of stone have been found, along with bones of deer, wild boar, wild bull, etc. In others the introduction of the use of metal is shown by the discovery of bronze tools and weapons, while additional evidence of progress in the arts is furnished by bones of domesticated animals, with fragments of pottery, rude cloth, and charred corn.

Peat Mosses.—In Denmark most interesting information has been obtained regarding the later parts of the Stone-Age in that country. In the peat mosses a succession of vegetation can be detected, the lower zone of peat containing remains of the Scotch fir, while the upper part is marked by the occurrence of the oak. The Scotch fir has never been known as an indigenous tree in Denmark, and the oak which took its place has in turn been succeeded by the beech. In the older parts of the peat stone implements are found, while in the later portions the works of art are of bronze.

Kitchen Middens.—Another kind of evidence regarding the Stone-Age is furnished by the Kjökkenmödding, kitchen middens or shell-mounds of Denmark. These are mounds made up of loose shells of the common cockle, periwinkle, oyster, and other edible molluscs—shell-refuse of the early races. They occur along the Danish coasts, and similar mounds have been noticed in different parts of the British islands. Among the castaway shells, tools of stone, bone, horn, and wood occur, but without any of metal; also pieces of rude pottery and traces of the use of fire.*

In Britain the close of the Stone-Age and the incoming of the use of

* See Morlot, *Bulletin de la Société Vandoise*, vi. Nilsson's *Stone Age*, translated by Lubbock; Sir John Lubbock's *Prehistoric Times;* Lyell's *Antiquity of Man*.

metal tools has not yet been so satisfactorily traced. The frequently found polished stone celts, and the neatly trimmed arrow-heads of flint, however, show that the older and ruder stone-weapons gave place to others of like material, but of far more cunning workmanship. It appears also that even after bronze came into use stone continued to be employed, as being probably a less costly and more easily obtained material. We even find proofs that the stone tools were sometimes elaborately cut and polished, to imitate the form of those which were cast in bronze.

The further tracing of the history of man belongs rather to a treatise on archæology than to a geological manual. In closing this outline it may not be inappropriate, however, to notice some of the proofs of geological changes which have been witnessed by man since he became an inhabitant of Britain. Reference has already been made to the evidence furnished by the ancient river-gravels and cave-earths regarding great vicissitudes which have passed over the surface of this country. We see how valleys have been deepened and widened, so as to alter the whole drainage of large districts; how the old rivers have left their terraces far above the limits of the present streams, and bear witness to a climate then much severer than that which we now enjoy, inasmuch as it was less removed from the Ice-age which had preceded it; how the long-extinct mammoth, rhinoceros, hippopotamus, and other lost mammals roamed over the country; how the caverns were haunted by extinct forms of hyæna, lion, and bear; how, of the forms of life which still survive, some, like the reindeer, elk, and musk-sheep, then abundant here, have now retreated to more northern latitudes, where they find that congenial climate which they formerly encountered in this country; how man, at first a savage, warring with rude implements of stone against the beasts around him,—then a more skilled hunter, with bow of horn and arrows tipped with flint,—then adding gradually to his comfort by gaining a knowledge of the use of metals, of the cultivation of corn, of the domestication of animals, and of the fabrication of woven textures, advanced step by step in civilisation,—now helped, perhaps, and now thrown back by the migration of other rude human tribes from what is now the mainland of Europe, until, at last, he comes within the pale of history, and is brought face to face first with the civilisation of Rome, and then with the humanising and elevating influences of Christianity.

Decay of Peat-Mosses, and Change of Climate.—Of the gradual change of climate, other proofs are afforded by the gradual decay of our peat-mosses. The wide areas of peat which cover so large a surface in Britain and in Ireland belong to a time when the rainfall was probably greater than it now is; for the peat, as a rule, is now no longer growing. On hill-tops and watersheds, where it once grew luxu-

riantly, to a depth of many feet, it is cracking up and wasting away. Rain, frosts, and runnels of water, continually act upon it, and carry its debris down to the low ground.*

Oscillations of Level of Land.—Evidence of recent oscillations of level of the land, with respect to the sea, in Britain, is furnished by the raised beaches and sunk forests.† The older raised beaches have been already referred to, as belonging to the submergence of the country during the later stages of the Glacial Period. Those which occur at a lower level than forty feet are probably all assignable to the human period, if indeed the forty-feet terrace itself does not mark the coast-line when the first men arrived in Britain. At Glasgow canoes have been found in the upraised silt of the estuary; and the country between the Firths of Clyde and Forth furnishes evidence of recent upheaval to the extent of about twenty-five feet.

Before the last elevations of the land there appears to have been a movement of subsidence, whereby peat-mosses and woods were carried down beneath the sea. The effect of the later upheavals would thus be to bring these submerged land-surfaces up again towards the level of the ocean, or above it. Evidence of the subsidence is to be found along many points of the coast-line of Great Britain and Ireland. Thus, on the Irish coast, "undisturbed peat bogs occur beneath the sand of the beach, stretching below the level of the lowest spring tides. Turf has lately been found beneath the mud of Wexford harbour. At numerous points along the south and west coast of Ireland it is a common practice of the country people to go to the head of the sandy bogs, at dead low water at spring tides, and dig turf from underneath the sand, and it has been equally noted in similar situations along the western and northern coasts. The stumps and roots of trees in the position of growth are found in this peat, clearly showing that it grew on the dry land; and its very general, we might almost say universal, occurrence round the coast, shows that no local position of sand hills or other barriers can account for the land having been dry, but that it formerly stood at a higher level, and is now beneath the sea in consequence of depression.

"There are many points on the coast of England also, where similar facts are observable. I dug a stump of a tree full of living pholades out of the turf at the margin of dead low water of a spring tide between the mouth of the Dee and the Mersey in the summer of 1837. Old land-surfaces have been found beneath the fens of Cambridge below the level of the sea." ‡

These movements serve to remind us that the great phenomena of

* See James Geikie on Peat Mosses and Buried Forests, and the Changes of Climate which they indicate, *Trans. Roy. Soc. Edin.*, xxiv. 363.

† See *ante*, pp. 331, 333. ‡ Jukes in last edition of the *Manual*.

upheaval and elevation do not belong to the far distant past, but are part of the present economy of nature, while still further indications of subterranean activity are given by the tremors and rumblings of the ground, hardly worthy of the name of earthquakes, which from time to time pass over various points of these Islands.*

Having brought down our geological history to what is known as the Recent Period—that is, the period characterised by the changes which civilised man has worked upon the surface of the earth—we might naturally be called upon to continue it even to the present day, and to give an account of the geological changes which have taken place during the lapse of human history, and of those which are now in progress around us. If this were done fully, it could be shown that the series of operations has been a perfectly continuous and equable one, even although our history of them might be incomplete. Whatever may have been the moral significance of the appearance of man upon the globe, it has, in a natural history point of view, been but the introduction of one more animal, superior to the rest in intelligence, and therefore in power. We cannot find any geological evidence of an interruption in what is commonly called the "course of nature," of any alteration in the physical laws, or of any traces of a general catastrophe, or cataclysm, or disturbance of any kind, occurring either just previous to, simultaneously with, or subsequently to, the introduction of man upon the globe.

Geology, by itself, shows us that the mechanical erosion of our present dry lands, either by the waters of the atmosphere or those of the ocean, has been going on uninterruptedly from a vast indefinite period to the present day. The elevation and depression of the surface of the solid crust of the globe above or below the surface of the ocean, seems equally to have acted from the earliest geological periods, just as it is now acting in the nineteenth century; and even if it could be proved that its former intensity of action must have been greater than now, we can show no proof of any sudden change in that intensity at any particular period either of geological or human history. The alteration in the rate of movement, if it took place at all during our geological history, was as gradual an alteration as the movement itself was always equable and gradual.

The secretion of solid matter from the ocean or the air by animal and vegetable life, and the deposition of that matter as a solid component part of the earth's crust, seems also to have been going on from an indefinite period of past time uninterruptedly down to the present day. The vast Coral reefs of the Indian and Pacific Oceans, rising

* The remaining paragraphs of this chapter are by Mr. Jukes, and formed the concluding chapter of the last edition.

from depths of at least 2000 feet, are grand monuments of the duration of this action. Mere centuries seem but units by which to count the time that must have elapsed since the commencement of these great bulks on the coasts of the submerged lands on which they began to grow. Making all allowance for the possibility of rapid growth in reef-making corals, we could not conceive it possible that over a space of a thousand miles in length, a foot could be added to the average height of the reef in less time than several years. Even on the supposition, then, of the slow subsidence of the bottom being continuous, the barrier reef of Australia (as one instance) must have taken several times 2000 years for its formation. But we have in reality no evidence to prove the subsidence of the base and the growth of the upper and outer edge to have been continuous, and it seems to have been stationary for the last 100 years at all events, and may have been so for many centuries; and such pauses in the movement appear rather to be the rule than the exception, so that the more we reflect on it the more does the date of the commencement of this great reef recede into the haze of past time. And what is true of this single instance is equally true for the atolls and barriers over the space of 6000 miles in the Pacific Ocean. Their very number, too, adds to the length of time that unfolds itself before our reason as a necessity for their formation, since it seems difficult to imagine them all to have begun at once, and the subsidence and upward growth always to have been in action over the whole area at once, and always to have been equal in amount, so as to reduce the time to a minimum. When all the significance of Darwin's explanation of the formation of Coral reefs is taken into account, no one can contemplate his map of their distribution without profound interest. They are the tombstones erected over the buried mountains of a submerged land, of the former existence of which we could have had no suspicion if it had not been for these piles of the skeletons of sea creatures thus heaped upon it during its gradual submergence.

If we turn from the Coral reefs and contemplate the extent and distribution of Volcanoes, we have to listen to another version of the same great story.* Beginning in the South Shetland Islands, in lat. 62° south, a chain of volcanoes may be followed through Tierra del Fuego, and along the Andes into Guatemala, and the West Indies and Mexico, and thence along the Cascade Range into Russian America, in lat. 62° north. This is connected by an east and west band, through the Aleutian Islands, with the Asiatic volcanoes, which, commencing in Kamtschatka, in 62° north, may be followed down the Kurile, and Japanese, and Philippine Islands, to the Moluccas, where they join on to another band, that, commencing on the coast of Burmah, sweeps

* For this purpose the map given in the *Earthquake Catalogue* of the British Association by Mr. R. Mallet, and his son Dr. J. W. Mallet, is a very convenient one.

through Sumatra and Java, Bali, Lombock, and Sumbawa. The two, uniting in the Moluccas, run thence along the north coast of New Guinea, and down through the intermediate islands to New Zealand, south of which the line seems to be continued through the Balleny Islands to Mount Erebus and Mount Terror, in lat. 78° south. These two volcanoes, rising to heights of 12,000 feet among the eternal snows of the Antarctic regions, lie between the same meridians of 160° and 170° east, as those of the north of Kamtschatka, so that we have here a sinuous volcanic band, extending north and south through 140° of the earth's polar circumference, or between 9000 and 10,000 miles. If we add the branches, and the American line, this length will be about doubled. The central volcanic islands of the Pacific, such as the Galapăgos, the Sandwich and Fidjee Islands, and those of the Indian Ocean, have also to be reckoned.

Except the raised coral islands of the Bermudas, and the non-volcanic islands of the West Indies, all the islands of the Atlantic, from Tristan d'Acunha to Iceland and Jan Meyen Island, are volcanic, and to these we must add the volcanoes of the Mediterranean basin.

The volcanoes of Central Asia are dying out simultaneously, as it appears, with the drying up of the waters of the internal basin of drainage, of which the Caspian and Aral Seas are the remains.*

* I do not know that it has ever been remarked that the Mediterranean, and its dependency the Black Sea, and all the countries the rivers of which flow into these seas, belong in reality to this great internal basin. The current always running in through the Straits of Gibraltar shows that supplies from the ocean are necessary to keep the Mediterranean up to the ocean level. If those Straits then were closed by land ever so little above that level, no overflow would take place out of the Mediterranean, and all southern Europe and North Africa would belong to the same internal basin of drainage, separate from that of the great ocean, which extends from the neighbourhood of St. Petersburg to the borders of China. It is remarkable that this internal basin would then be connected in the most intimate manner with the great complex mountain chain of the Old World, running east and west from Spain and Morocco into China. If we regard the Pyrenees and the Atlas as two parallel cordilleras of this chain, we have the table-land of Spain and the western extremity of this basin between them. We must then look to the mountains of Germany and the Valdai Hills of Russia and the Altai mountains of Asia as the northern ranges of this great chain, throwing off the drainage of its outer slopes to the Arctic Ocean, and regard the Mongolian and Himmalayah mountains as its eastern and southern borders in Asia, while in Africa that southern border must be extended to the mountains from which the Nile descends. All the high lands between these limits consist of long, but often-interrupted, east and west ranges, together with lofty table-lands singularly alternating with deep basins, one of which, that of the Dead Sea, is so greatly desiccated that its waters are now 1300 feet below the ocean level. The Caspian Sea even has shrunk to a depth of 80 feet, and the Mediterranean, and therefore the Black Sea, would have shrunk had it not been for the supply through the Straits of Gibraltar. Two broad spaces of low land—the one in Russia, between the Carpathian and Ural mountains, and the other in Africa, between the Desert and the Libyan Gulf—seem to lead into this interior basin. Was it formerly connected with the main ocean through these spaces?

When the history of the formation of the countries occupied by this singular complex belt of broken country, which comprises both the loftiest peak and the lowest spots of dry land in the world, comes to be completely written, the connection of this anterior basin of

Throughout all the vast spaces thus briefly mentioned there occur volcanic cones, composed of heaps of ejected cinders and ashes, with occasional lava-flows, all braced together by injected dykes and veins of lava. These external pustules, symptoms of the internal throes of the more deeply-seated masses of molten rock, have all been accumulated in the same way that we see them now being accumulated. Their present intermittent action, indeed, is obviously but a continuation of that which has been going on from their commencement. We know that many of them have lain dormant for great spaces of time, and then burst forth again into activity. Vesuvius is but a small example of them, and it must continue for an immense period of time to add to its external size, before it could hope to rival the vastly preponderating bulk of Etna. Yet we know that Vesuvius was dormant for several centuries before our era, and that although it has continued active ever since, yet the subsequent accumulations have not, to say the most, doubled the size of the mountain which existed before the year A.D. 78. Etna, from all the descriptions of the earliest writers, was very much of the same height and bulk 2400 years ago which it attains now, so that Pindar could speak of its being the pillar of Heaven and the nurse of "*everlasting frost*," as well as "containing the fountains of unapproachable fire." It bears on its flanks volcanic hills of no inconsiderable magnitude, and Vesuvius might be almost hidden away in the valley called the Val del Bove, which runs down one side of Etna. Its base would cover an English county, and its summit is nearly 11,000 feet high, the whole being made up internally of numerous small cones of ejection buried from time to time under the vast piles of dust and ashes, and the rivers of molten rock which have proceeded from its dominant centre.

If we reckon from what we *know* of the mode of action in the formation of volcanic mountains, taking into account all the pauses which occur between the periods of action, to what date are we to refer the commencement of the ejections which formed the old mountain of Vesuvius as it stood before the time of Pliny? and to what more vast and dim antiquity are we to refer the beginnings of Etna? But if these two mountains give rise to such unanswerable questions, what shall we say when we come to the general examination of the far larger, far loftier, and still more numerous, volcanic cones which rear their heads along the lines just now spoken of as traversing whole continents and crossing great oceans? The number of cones must be taken into account, because, while we know that all the cones of a great district are often dormant together for long periods, we do not know of any instances in which they all become simultaneously active. A great

drainage with the mountain-ranges and table-lands will doubtless be found to be an important part of it.

eruption in one is indeed often sympathised with by others, so far as the emission of smoke or slight symptoms of activity are concerned, but no great additions to the bulk of these piles are ever made simultaneously in all.

It is not of course intended to assert that the commencement of all the great active volcanoes of the world dates from a period later than the creation of the human race, though most of them seem to be no older than the existing species of Mollusca. Whatever may have been the dates of their origin, however, their action has been continued through the Recent period, and therefore in part belongs to it. It is clear, also, that since the ejection of these piles, so many of which consist of loose materials, often so pumiceous as to float in water, no natural deluge could have swept over the dry land without leaving evident traces of its passage, neither can the cones have been ever quietly submerged beneath the sea without traces of such an occurrence being discernible.

Earthquakes, which are so commonly the accompaniments or precursors of volcanic eruptions, ought also to be described in our continuation of geological history from human records. They are obviously the external symptoms of the movements generated deep in the earth's crust by the action of the heated interior, when that movement becomes convulsive instead of equable. Mr. Mallet has given an admirable resumé of their history from the year B.C. 1606 down to the year A.D. 1842. M. Perrey of Dijon continues the account to 1850. No less a number than between 6000 and 7000 separate recorded earthquakes are discussed by Mr. Mallet in the reports attached to his "Catalogue." During the last four years embraced by his list, he mentions upwards of 400 earthquakes, or an average of about two a week.* If, therefore, we allow for many unrecorded shocks, which were either too slight for notice or occurred in parts of the earth where no record of them was made, we shall perceive that the crust of the earth is in fact in a perpetual state of vibration and trembling, now in one part, now in another. If these movements are so often felt even at the surface, it seems that the internal and deeper seated parts of the earth's crust must be still more frequently affected, and by movements of far greater magnitude and intensity than those which reach that surface.

Mr. Mallet discusses the relations of earthquake energy to both time and space, the distribution of earthquakes over the surface of the globe, and their connection with volcanic districts; he also describes the laws of motion which they seem to observe, comparing them with the vibrations produced artificially by great blasts of gunpowder, and gives rules for finding the depth of the origin of the shock, and direc-

* See the *Earthquake Catalogue* of the British Association already cited.

tions for observing them more systematically than has hitherto been done.

These four great actions then—the destruction of rock by chemical decomposition and mechanical erosion,—the formation of rock by chemical or organo-chemical consolidation, and by mechanical deposition—the intrusion of igneous rock from below into or over aqueous rock—and the bodily elevation and depression of different parts of the earth-crust thus elaborated—are still going on now, as they have ever done, from the earliest periods of geological history. Some knowledge of their mode of action now is necessary as a preliminary to the study of their past results, and they were accordingly described in an earlier portion of this work; but the geological history of the formation of the crust of the earth would be obviously incomplete without some mention of them again at the close of the story.

In like manner an account of existing plants and animals, the laws regulating their structure, their classification, their mutual relations, and their geographical distribution, would form a fitting close to the palæontological account of the extinct species of past times. The existing Flora and Fauna which inhabit the globe are the result of the variation and multiplication of species that have been going on uninterruptedly along with the physical changes that have acted on its crust. No violent break in the continuity of the chain of descent, no universal destruction, no sudden end to one population and simultaneous commencement of another, can be proved to have ever happened, or even shown to be probable.

Life, to the fullest extent in number of individuals, and to the utmost variety of forms that circumstances would allow, and with the most far-seeing and omniscient provisions for the wants and necessities of the future, has evidently been the all-wise and all-good law of creation, governing both animate and inanimate processes from the earliest geological period down to the present time.

APPENDIX.

I. ON GEOLOGICAL SURVEYING.

It has been suggested to me that a few words on the mode of setting to work to make a geological examination of a country would be found useful. Being provided with a large and small hammer, a pocket clinometer and lens, and in some cases a small bottle of dilute acid, the next requisite is to get a good map of the ground to be examined. The scale of the map should be large in proportion to the minuteness and detail of the intended survey. The Ordnance maps, on the scale of six inches to the mile, are usually large enough for the most minute and accurate work, but for any amateur work those on the scale of one inch to the mile are generally large enough, and their execution is in all the later maps very good. In foreign countries maps on a much smaller scale have generally to be used, and often very imperfect or inaccurate maps.

Supposing the observer to be provided with the best attainable map, and to have unlimited time at his command, he may first proceed to make himself acquainted with the geography of the country by traversing it in various directions, viewing it from its hill-tops, and getting a thorough knowledge of its external form. In doing this he must note the lithological constitution of its most prominent rock masses, and determine by the methods pointed out in Chapter IV. whether they are stratified aqueous rocks, or unstratified igneous rocks, or partly of one and partly the other character.

He may then commence his more detailed survey by marking down on his map every exposure of rock on the exact space it occupies, and colouring that space with whatever tint he may select, to denote the lithological or geological character of the rock. If his map be not sufficiently large to admit of this, he must describe the rock in his note-book, with a reference to the exact spot, as accurate as he can contrive to make it.

If he find nothing but igneous rocks, he must set himself to determine the different kinds to which they belong, and mark down on his map the area occupied by each. On the Geological Survey various shades of carmine, lake, and scarlet, are employed for igneous rocks. Other and contrasting colours are used for the aqueous rocks. Thus the Cambrian and Silurian formations are indicated by various shades of purple, the Oolitic series by yellows, the Cretaceous by greens, the Tertiaries by browns.*

In determining the areas occupied by each kind, the observer will of course note the relations of each to the other, and whether one be intrusive into the other, or what other connection they may have.

* The student who wishes to pursue this subject for himself should procure a copy of the large Index sheet of colours and signs published by the Geological Survey, price 5s. It can be had at Messrs. Stanford, Charing Cross, London; W. and A. K. Johnston, Edinburgh; Hodges and Smith, Dublin.

In examining stratified or aqueous rocks, he will in the first place seek for some locality where the best "section" of these can be seen, as described in Chapter VIII. The sea-coast, or the banks of a river, or an inland cliff, will be most likely to afford him the best natural exposure of the beds; a railway cutting, or a road-side cutting, or a deep ditch, or any other longitudinal trenching of the ground, will give him the best artificial sections. Failing these, he must visit all the quarries or pits of the district, must inquire after all wells and mining shafts, and must get the most accurate accounts he can of the nature of the beds that were passed through, and of their "lie and position;" that is to say, the way in which each lay in the ground, and the depth and thickness of each, making particular inquiries as to the "dip" of the beds, or the direction in which they "deepened," and the rate of deepening. In some districts the rate of deepening is reckoned at so many inches in a yard, or so many feet or yards in a hundred; in others it is stated as a dip of a foot or a yard in so many feet or yards. Geologists usually state the number of degrees at which the beds incline from a horizontal plane. Table I. will give the means of translating either of these modes of expression into any of the others, it being understood that the nearest whole numbers are taken, and those figures only given which will be found useful in practice.

The observer will mark on his map by a small arrow the direction of the dip, and write the angle of dip in figures alongside the arrow, or he will enter the information in his note-book, to be transferred to a map subsequently if necessary. In any operation requiring greater exactness, more accurate instruments than a pocket clinometer will of course be used, and the calculations be made accordingly.

TABLE I.

Showing different modes of stating the Dip.

In this Table, only those numbers are given which are likely to be found of use in practice, and that chiefly to the nearest whole number, omitting fractions.

Angle of Dip.	Incline of	Ft. or Yds. in 100.	Inches in a Yard.	Angle of Dip.	Incline of	Ft. or Yds. in 100.	Inches in a Yard.
1°	1 in 57	1¾	0½	30°		58	21
2°	1 in 29	3½	1	35°		69	25
3°	1 in 19	5¼	2	40°		83	30
4°	1 in 14	7	2½	45°	1 in 1	100	36
5°	1 in 11	9	3	64°	2 in 1		
6°	1 in 10	10	4	72°	3 in 1		
7°	1 in 8	12¼	4½	76°	4 in 1		
8°	1 in 7	14	5	79°	5 in 1		
9°	1 in 6	16	6	81°	6 in 1		
11°	1 in 5	20	7	82°	7 in 1		
14°	1 in 4	25	9	83°	8 in 1		
18°	1 in 3	33	12		etc.		
20°		36	16				
24°		44	17				
26°	1 in 2	50	18				

In highly-inclined rocks dipping in different directions, the amount of dip varies so frequently that minute accuracy in observing it is often waste of time; but the strike of the beds, and their course across the country, should be carefully observed.

When the surface of the ground is very uneven, the observer must recollect that the strike of the beds will not correspond with their line of outcrop on the map, or will only correspond with it on the great scale—that is, when the length to which the bed may be traced is very large compared with the undulation of the surface. When the angle of dip is low, a comparatively small undulation of the ground will of course cause the outcrop of a bed to deviate widely from the line of its strike; and, on the other hand, a slight change in the strike, or in the amount of the dip of a bed, will produce a much greater effect than when the inclination of the dip is a high one.

The observer must endeavour to keep in his mind the ascertained thickness of the group of rocks he is tracing, and all their possible changes in dip and strike, and the consequent relations of these to the different features of the surface, so as to guard himself against being deceived or led astray. He must also not spare his own labour, but search diligently every square yard of ground on which there is any possibility of rock being exposed, so that he may be sure of being acquainted with every observable fact before he draws his conclusions. If time or the means at his disposal do not allow of his survey being thus exhaustive, he must always entertain a certain amount of diffidence on the conclusions he arrives at, and hold them open to future correction.

If he find in tracing stratified rock that the appearances are such as to render probable the existence of a fault or dislocation, he must be particularly on his guard against allowing his mind to jump to the conclusion that it exists, before he has put that existence beyond doubt. Faults or dislocations are doubtless much more numerous than we are aware of, but for that very reason great care should be taken not to introduce them on geological maps, except in the precise situations and with the precise directions which they really hold. I speak in this matter from personal experience, and with an ample measure of remorse for my own sins in this matter. It is the error into which many geologists most easily fall, and which they ought to be most warned against for the future. Most especially should the greatest caution be exercised before the first dislocation is laid down in a district. If one line of fault be proved beyond all question to exist, others must almost necessarily be present, either parallel to it, or more or less nearly at right angles to it. Before one fault then be laid down, the observer should require an amount of evidence which can allow of no other possible solution than the fact of a dislocation; but having proved that, and having accurately determined its direction, a much less amount of evidence may be reasonably admitted for the existence of the corresponding dislocations. Even when, in making observations in mining districts, he is assured of the existence of a fault by the miners themselves, the observer must be on his guard, and carefully ascertain that by a "fault" the miners mean really a "dislocation," and that their statements as to its "throw" or its "width" are such as he clearly understands, and are correctly stated by the men themselves.

Keeping these precautions in his mind, the observer may, from detached observations, lay down on his map the boundary line between two different sets of beds with more or less accuracy, according to the number of his "data," or, in other words, the number of places in which the rocks are clearly exposed. By drawing the upper and lower boundary of a set of beds, and observing their average inclination, it is obvious that he can calculate their thickness; and by doing this for the outcrop of several sets of beds, he can determine approximately the depth at which the lower set will be found

under any given spot of the upper. For this purpose he must assume the surface of the ground to be a plane, and then, if necessary, measure its undulations, and allow for any departure from the true plane. The thickness of the beds whose outcrop has been traced, or the depth attained in a given horizontal distance by any one of them, may be learnt either by protraction and measurement, or by calculation.

In vein-mining the "underlie" is reckoned from the perpendicular and not from the horizontal, and the distances used are fathoms, but the inches in a yard column can be used to ascertain the angle from the horizontal, by merely halving the quantities given for the fathom, and taking the complement of the angle. For example :—A lode underlying 3 ft. 6 in. a fathom, or 42 inches in 6 feet = 21 inches in 1 yard, has an angle of 30°, the complement of which is 60°, which is the inclination of the vein from the horizontal.

The following table will save trouble in most instances; the thickness measured at right angles to the dip, and the depth measured at right angles to the horizon, being given for every degree up to 20°, and for every 5° after that, in a distance of 100 (feet, yards, etc.), measured horizontally directly across the strike of the beds :—

TABLE II.

Depth and Thickness Table.

Horizontal distance = 100.*

Angle of Dip.	Depth.	Thickness.	Angle of Dip.	Depth.	Thickness.
1°	1·7	1·7	18°	31·8	30·9
2°	3·5	3·5	19°	34·5	32·6
3°	5·3	5·3	20°	36·6	34·2
4°	7·0	7·0	25°	46·9	42·3
5°	8·8	8·7	30°	58·0	50·0
6°	10·6	10·5	35°	70·5	57·4
7°	12·3	12·2	40°	84·2	65·6
8°	14·1	13·9	45°	100·0	70·7
9°	16·0	15·6	50°	119·0	76·6
10°	...	17·4	55°	143·0	81·9
11°	19·5	19·1	60°	174·0	86·6
12°	21·4	20·8	65°	214·0	90·6
13°	23·2	22·5	70°	275·0	94·0
14°	25·2	24·2	75°	368·0	97·0
15°	26·9	25·9	80°	575·0	98·0
16°	28·7	27·6	85°	1143·0	99·0
17°	30·7	29·2			

As this table is one giving the solution of a right-angled triangle for each angle specified, it may be used to find any dimension which can be stated

* It is sometimes more convenient to consider the horizontal distance 1000, when the decimal point in the table disappears, and the numbers given become 17, 35, 53, etc., instead, of 1·7, 3·5, 5·3, etc.

in the form of a right-angled triangle, as for calculating the space between the outcrop of two beds of which the angle of dip is known, and the thickness between them; the distance which any bed, of which the depth and inclination are known, will require before its outcrop at the surface can occur; and so on.

By means of this table, also, the probable "throw" of faults can be ascertained, where the broken ends of a bed on opposite sides of a fault can be found, and a certain mean angle of dip assigned to the whole mass. If, for instance, there be a set of beds, including one particular bed A B C, which are traversed by a fault FF either at right angles to their strike, or obliquely, as drawn in the Fig., and the mean dip of the beds be 30°, and the outcrops of the broken bed A B C be found on opposite sides of the fault in such a position that the strike of the piece B C which is "upthrown," (when produced if the fault be oblique so as to be measured at right angles to A B), be found to be 150 yards (or any other distance) apart from the strike of the "downthrown" piece; then, as the table will give us the depth which the downcast piece has attained at the distance of 150 yards, and the depth accordingly which it has on one side of the fault, while the upthrown piece crops out exactly on the other side of the fault, that depth is of course the "throw" of the fault. If it be 100 yards, then, with a dip of 30°, the table shows a depth of 58 yards, which is the amount of the downthrow; if 150 yards, it will of course be $58 + \frac{58}{2}$ (or 29) = 87; if 200 yards, it will be 116, and so on; and if the dip had been 12°, and the horizontal distance 100 yards, then the throw would be 21·4 yards; if 1000 yards, the throw would be 214 yards, and so on. The table is indeed of continual use to the practical geologist, in checking his preconceptions as to depth and thickness, amount of dislocations, etc. etc. etc.*

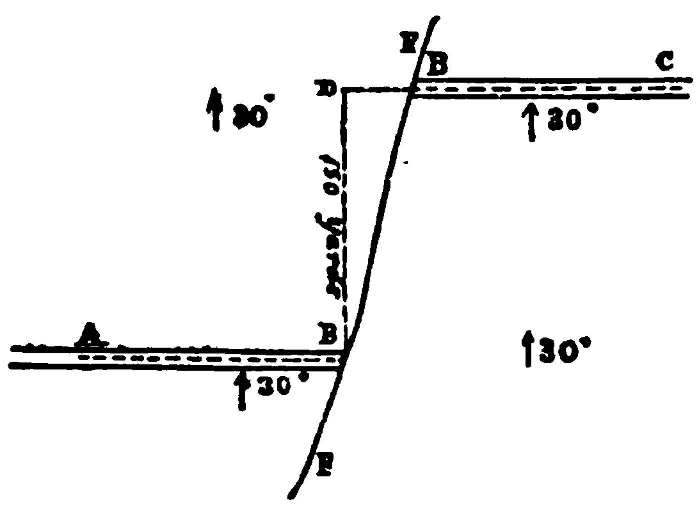


Fig. 167.
Ground-plan of a fault, to illustrate calculation of throw of fault by table.

Construction of Sections.—The formation of a geological map, by joining together the separate appearances of the outcrop of beds at the surface, is only a part of the work necessary to convey a knowledge of the geological structure of a country. This map may often be taken as a horizontal section of the district, formed by cutting it by a horizontal plane at a certain level, and removing all the matters above that plane. In order fully to understand, however, the "lie and position" of the rocks, it is necessary to have a vertical longitudinal section which shall show the direction and amount of their inclination beneath the horizontal plane, and the depth attained by any particular bed under any spot at a given distance from its outcrop. For this purpose a horizontal datum-line is assumed, which is generally the level of the sea, and a line of country is selected for the section, which is generally taken at right angles to the strike of the beds. The undulations of the ground along the selected line are then marked in, so as to give the proper heights for the different points above the assumed datum-line. If the scale for horizontal and

* Messrs. Troughton and Simms of Fleet Street, London, have prepared, at my suggestion, a little ivory protractor, on which this Table and part of Table I. are engraved, together with the scales of the six-inch and one-inch maps, which the observer will find very useful to have in his notebook or map-case. Its price is 10s.

vertical distances be the same, the result will of course give us a true profile or outline of the features of the ground. This, however, often requires the section to be drawn, either to such a great length as to be unmanageable, or on such a small scale that the vertical distances are too minute for distinctness. It is in such cases advisable to sacrifice the correct outline and enlarge the heights to several times their due proportion, which of course involves a corresponding distortion in the angle of inclination of the beds and their apparent thickness, and so on. If, however, the two scales be given, it is easy, of course, to correct the apparent distortion by calculation and measurement, and learn the true facts from the section. Having got the outline of the ground, we must then insert in their proper places the outcrop of the different beds and formations, or masses of igneous rock, faults or veins, etc., as noted on the map or in the observations in the notebook, and draw them at their proper angle if the section be on the natural scale, or at a calculated angle if it be distorted. This calculation can easily be made from Table II. by ascertaining what depth any bed, etc., would reach in any given horizontal distance at the real angle, and drawing them so as to be at that depth at that horizontal distance in the distorted section.

When a section is made across a greatly disturbed district, parts of it will almost of necessity be drawn, not directly across the strike of the beds, or with their dip, but more or less obliquely to it. Sometimes the section might unavoidably run along the strike of the beds for some distance; if so, the beds will of course appear to be horizontal in that part of the section, since they will dip either directly from or directly towards the spectator, and will therefore incline neither to his right nor to his left hand. When the section runs directly across the strike, it will of course represent the true dip of the beds. If it go obliquely across the strike, then it will represent the dip at some intermediate angle between the horizontal line and the true dip. As the calculation of the proper correction to be made for this obliquity in the line of section is rather troublesome, and as in some instances it is advisable that it should be given correctly, not only for the purpose of determining the depth of beds, but also for drawing the true angle of lines of faults, joints, veins, dykes, and cleavage planes, the following table (Table III.) is added. This is taken from one which I constructed for my own use when running sections in North Wales, but the nearest whole numbers are only stated in it, and the lower degrees of dip and obliquity omitted, as neither they nor the minutes of degrees are practically useful.

The angles stated in the first column are those between the direction of the line of section and that of the dip of the bed, fault, vein, cleavage plane, or other inclined line that is to be inserted in the section. This insertion can be correctly made (in a section on the natural scale), by seeking in the table the number which will be found at the intersection of the requisite horizontal and vertical columns.

If, for instance, a section be drawn along a line which crosses the line of dip at 55°, and the beds at one part dip at 65°, they would be represented as they would be seen in a natural vertical cliff if one ran along that line of section, by drawing them at an angle of 51°. If they changed their strike a little farther on, so that the straight line of section crossed their new dip at an angle of 75°, their apparent dip should be reduced to 29°, giving them the requisite curve between the two dips at the part where the beds curved their strike.

The "angle between the direction of the dip and that of the section" is always to be calculated on that side of the section where the angle between them is less than 90°, and the direction of the dip in the section is to be drawn accordingly. If, therefore, the angle between them be large, and the

TABLE III.

Oblique Section Table.

Angle between the direction of the dip and that of the section.	Angle of the Dip.										
	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.
Degs.	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**89**
40	32	37	42	47	53	58	64	70	77	83	88
45	30	35	40	45	51	56	62	69	76	83	88
50	28	32	37	42	48	54	60	67	74	82	88
55	25	29	34	39	45	51	57	65	73	81	88
60	22	26	31	35	41	47	54	62	70	80	88
65	19	23	27	31	36	42	49	57	67	78	87
70	16	19	22	26	30	36	43	52	63	75	87
75	12	14	17	20	24	29	35	44	56	71	86
80	8	10	12	14	17	20	25	33	44	63	84
85	4	5	6	7	8	10	13	18	26	45	79
89	1	1	1	1	2	2	3	4	5	11	45

Note.—This table, in a fuller form, is given in the Appendix to the Geology of the South Staffordshire Coal-field.—(*Mems. Geol. Survey.*)

direction of the section be slightly changed at one point, so as to shift the side on which the lesser angle lies, the apparent dip in the section will have its direction changed, although no change has taken place in reality. Suppose, for instance, the cleavage planes in a certain tract of country dip due N. at 80°, and a section be taken across that ground in a direction from W. 5° S. to E. 5° N. up to a certain point, the spectator being supposed to be looking towards the north, the angle between that section and the dip of the cleavage planes being 85°, they will be drawn in the section as dipping at 26° to the east or towards the spectator's right hand. If, however, the direction of the section be changed at that point, and it be continued on a line from W. 5° N. to E. 5° S., the direction of the dip of the cleavage planes must of course be altered, and they must be drawn as if dipping at 26° to the west, or towards the spectator's left hand. It is obvious that this would be their appearance if two real cliffs were to be formed running in the directions above named, and meeting in a corner at an angle of 170°. The cleavage planes would go straight across from the one to the other, and would rise from the base towards the summit of the cliff on either hand of the spectator, or dip from the summit towards the foot of the cliff on each side of the spectator, as he looked northwards towards the junction of the two cliffs.

It must be recollected that if the section be not drawn on a natural scale, but on two scales differing in height and length, the dip must first be drawn

with the requisite amount of exaggeration, as before described, and then that must be measured and the proper correction applied to it if the line of section be oblique to it. This, however, will not often be required except in mining sections.

One error to be guarded against in constructing sections is the very natural one of supposing that all the intermediate pieces of ground, between the parts where the outcrops of the beds are to be seen, are occupied by beds dipping at the same angle, or even in the same direction, as they do in those parts. It may happen that the outcrop of beds is visible only in those places where they are more highly inclined than usual. It may even be the case that only those parts which dip in one direction are visible, while the intervening concealed parts dip in another direction. Very serious errors have in this way crept into many sections published by even high authority. It is, however, one that should be strenuously guarded against, for which purpose the sections lately published by the Geological Survey in Ireland have only those beds engraved on them which are certainly known to exist, the intermediate spaces being left blank, and as far as possible omitted in the calculations for thickness.

The student may be often at a loss to find the real heights of the places his section passes over, as levelling is a troublesome and sometimes expensive operation. The Aneroid Barometer will often assist him in determining the highest and lowest points of his section with comparative facility. If, however, this be unattainable, he will almost always be able to learn the height of some of the canals, railways, or roads, or the height of some river or other object in his neighbourhood, from which the altitude of other points may be estimated with sufficient accuracy for his purpose. If he once get the height of any point in the main river of a district, he will know that no piece of ground from which the water flows towards that point can be at a lower level than it, and will thus get a limit in that direction for the depth of his undulations, while the altitude of the highest hill in his district will give him a limit in the other direction, and by constantly referring to these two he will generally be able to construct a geological section with sufficient approximate accuracy for ordinary purposes. An error of twenty or thirty feet will be of no real importance to him, when he recollects that in his section it is probably included in the breadth of a pencil line.

Sections for practical operations, such as mining or engineering, or in those cases where important conclusions are to be drawn from the relative heights of particular points, are of course to be treated on quite different principles from those geological sections which are often only diagrammatic representations of the general facts as to the superposition of groups of beds, useful to ascertain only their average thickness, or to point out their mode of occurrence beneath the surface.

II. SYNOPSES OF THE ANIMAL AND VEGETABLE KINGDOMS.

KINGDOM ANIMALIA.*

SUB-KINGDOM VERTEBRATA.

PROVINCE I.—MAMMALIA.

Class I.—Mammalia.

Subclass I.—Monodelphia.

Order 1. PRIMATES . . .	Man, Apes, Lemurs.
,, 2. CHEIROPTERA . .	Flying Foxes, Vampires.
,, 3. INSECTIVORA . .	Hedgehog, Shrew, Mole, Galeopithecus.
,, 4. RODENTIA . . .	Rat, Hare, Squirrel.
,, 5. HYRACOIDEA . .	Hyrax.
,, 6. UNGULATA	
1. ARTIODACTYLA	Pig, Hippopotamus, Camel, Deer, Ox, *Anoplotherium*.
2. PERISSODACTYLA	Horse, Rhinoceros, Tapir, *Palæotherium*.
,, 7. *TOXODONTIA* . .	*Toxodon*.
,, 8. SIRENIA . . .	Manatee, Dugong, *Halitherium*.
,, 9. PROBOSCIDEA . .	Elephant, *Mastodon*.
,, 10. CARNIVORA . . .	Lion, Dog, Bear, Seal.
,, 11. CETACEA . . .	Whale, Porpoise, *Zeuglodon*.
,, 12. EDENTATA . . .	Sloth, Ant-eater, Armadillo, *Megatherium*.

Subclass II.—Didelphia.

,, 13. MARSUPIALIA . .	Kangaroo, Opossum.

Subclass III.—Ornithodelphia.

,, 14. MONOTREMATA . .	Echidna, Ornithorhynchus.

PROVINCE II.—SAUROPSIDA.

Class I.—Aves.

Order 1. *SAURURÆ* . . .	*Archæopteryx*.
,, 2. RATITÆ	Apteryx, *Dinornis*, ostrich.
,, 3. CARINATÆ . . .	Penguin, Gull, Fowl, Pigeon, Sparrow, Eagle, Parrot, Duck, Cormorant.

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* This scheme of the Animal Kingdom, originally drawn up for this work by Professor Huxley, has been revised by him for the present edition. The names of those orders and genera which are entirely extinct are printed in italics.

Class II.—Reptilia.

Subclass I.—Suchospondylia.

Order 1.	*ORNITHOSCELIDA*	*Megalosaurus, Iguanodon, Thecodontosaurus.*
„ 2.	*PTEROSAURIA*	*Pterodactylus, Rhamphorhynchus.*
„ 3.	*DICYNODONTIA*	*Dicynodon, Oudenodon.*
„ 4.	CROCODILIA	Alligator, Crocodile, *Teleosaurus.*

Subclass II.—Erpetospondylia.

„ 5.	*PLESIOSAURIA*	*Plesiosaurus, Nothosaurus.*
„ 6.	LACERTILIA	Lizard, Chameleon, Blindworm.
„ 7.	OPHIDIA	Python, Rattlesnake.

Subclass III.—Pleurospondylia.

„ 8.	CHELONIA	Tortoise, Turtle.

Subclass IV.—Perospondylia.

„ 9.	*ICHTHYOSAURIA*	*Ichthyosaurus.*

PROVINCE III.—ICHTHYOPSIDA.

Class I.—Amphibia.

Order 1.	SAUROBATRACHIA	Proteus, Salamander.
„ 2.	*LABYRINTHODONTA*	*Archegosaurus, Mastodonsaurus.*
„ 3.	GYMNOPHIONA	Cœcilia.
„ 4.	BATRACHIA	Frog, Toad.

Class II.—Pisces.

Order 1.	DIPNOI	Lepidosiren.
„ 2.	GANOIDEI	Lepidosteus, Sturgeon, *Lepidotus.*
„ 3.	TELEOSTEI	Perch, Cod, Salmon.
„ 4.	ELASMOBRANCHII	Sharks, Rays, and Chimœræ.
„ 5.	MARSIPOBRANCHII	Lamprey, Hag.
„ 6.	PHARYNGOBRANCHII	Amphioxus.

SUB-KINGDOM ANNULOSA.

PROVINCE I.—ARTHROPODA.

Class I.—Insecta.

Order 1.	HYMENOPTERA	Saw-fly, ichneumon, bee.
„ 2.	COLEOPTERA	Beetles.
„ 3.	NEUROPTERA	Dragon-fly, white ant.
„ 4.	STREPSIPTERA	Stylops.
„ 5.	LEPIDOPTERA	Butterfly, moth.
„ 6.	DIPTERA	House-fly.
„ 7.	ORTHOPTERA	Cricket, locust, earwig.
„ 8.	HEMIPTERA	Bug, cicada, aphis.
„ 9.	APTERA	Flea.

Class II.—Myriapoda.

Order 1.	CHILOPODA . . .	Centipede.
,, 2.	CHILOGNATHA . .	Millipede.

Class III.—Arachnida.

Order 1.	ARTHROGASTRA . .	Scorpion.
,, 2.	ARANEINA . . .	Spiders.
,, 3.	ACARINA . . .	Mites and ticks.
,, 4.	PYCNOGONIDA . .	Pycnogonum.
,, 5.	ARCTISCA . . .	Water-bears.
,, 6.	PENTASTOMIDA . .	Linguatula.

Class IV.—Crustacea.

Order 1.	PODOPHTHALMIA .	Lobster, crab.
,, 2.	BRANCHIOPODA . .	Daphnia, apus.
,, 3.	OSTRACODA . . .	Cythere, cypris.
,, 4.	PECTOSTRACA . .	Barnacles, acornshells, Rhizocephala.
,, 5.	STOMAPODA . . .	Squilla.
,, 6.	EDRIOPHTHALMIA .	Isopods, amphipods, læmodipods.
,, 7.	MEROSTOMATA . .	King-crab, *Eurypterus*.
,, 8.	*TRILOBITA* . . .	*Trilobites*.
,, 9.	COPEPODA . . .	Cyclops, argulus, lernœa.

PROVINCE II.—ANNULATA.

Class V.—Annelida.

Order 1.	CHŒTOPHORA . .	Nereis, serpula, lob-worm, Echiurus, Sipunculus, earth-worm.
,, 2.	DISCOPHORA . .	Leech.

Class VI.—Chœtognatha.

Order 1.	SAGITTIDA . . .	Sagitta.

PROVINCE III.—ANNULOIDA.

Class VI.—Scolecida.

Order 1.	TREMATODA . . .	Fluke.
,, 2.	TÆNIADA . . .	Tape-worm.
,, 3.	ACANTHOCEPHALA .	Echinorhynchus.
,, 4.	NEMATOIDEA . .	Thread-worm, hair-worm.
,, 5.	TURBELLARIA . .	Planaria.
,, 6.	ROTIFERA . . .	Rotifer, brachionus, lacinularia.

Class VII.—Echinodermata.

Order 1.	HOLOTHURIDEA . .	Sea-cucumbers, trepang.
,, 2.	ECHINIDEA . . .	Sea-urchins.
,, 3.	OPHIURIDEA . .	Sand-stars.
,, 4.	ASTERIDEA . . .	Star-fish.

Order 5.	CRINOIDEA . .	. Feather-star, stone-lily.
" 6.	*BLASTOIDEA* .	. *Pentremites.*
" 7.	*CYSTIDEA* . .	. *Cryptocrinus, apiocystites.*
" 8.	*EDRIOASTERIDA* .	. *Agelacrinites.*

SUB-KINGDOM MOLLUSCA.

PROVINCE I.—ODONTOPHORA.

Class I.—Cephalopoda.

Order 1.	DIBRANCHIATA . .	Squid, argonaut, poulpe, cuttle-fishes, *belemnites.*
" 2.	TETRABRANCHIATA .	Nautilus, *ammonites.*

Class II.—Pteropoda.

Order 1.	THECOSOMATA . .	Hyalæa, cresеis (dentalium ?) *
" 2.	GYMNOSOMATA . .	Clio, pneumodermon.

Class III.—Pulmo-Gasteropoda.

Order 1.	INOPERCULATA . .	Helix, limax.
" 2.	OPERCULATA . .	Cyclostoma.

Class IV.—Branchio-Gasteropoda.

Order 1.	†PECTINIBRANCHIATA	Whelk, periwinkle.
" 2.	SCUTIBRANCHIATA .	Haliotis (ear-shell).
" 3.	TUBULIBRANCHIATA .	Vermetus.
" 4.	CYCLOBRANCHIATA .	Limpet, chiton.
" 5.	NUDIBRANCHIATA .	Doris.
" 6.	TECTIBRANCHIATA .	Aplysia.
" 7.	INFEROBRANCHIATA .	Diphyllia.

PROVINCE II.—LAMELLIBRANCHIATA.

Class V.—Lamellibranchiata.

Orders.	No good orders have yet been established, neither Dimyaria and Monomyaria, ‡ nor Pleuroconchs and Orthoconchs, being good natural divisions.	Oyster, mussel, unio, cockle, venus, and all ordinary bivalves.

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* There is much to be said for the proposition to make *Dentalium* the type of a distinct order, *Scaphopoda.*

† These groups are artificial, and must be looked upon as provisional, until the Gasteropoda are more thoroughly examined.—T. H. H.

‡ All Monomyaria, except the adult Mulleria, are marine, which is one reason for noting the distinction.

PROVINCE III.—MOLLUSCOIDA.

Class VI.—Brachiopoda.

Order 1.	BRACHIOPODA ARTICULATA .	Terebratula, *leptæna, spirifera, producta.*
„ 2.	BRACH. INARTICULATA . .	Lingula, orbicula, crania.

Class VII.—Polyzoa.

Order 1.	CHEILOSTOMATA . . .	Flustra, eschara.
„ 2.	CTENOSTOMATA . . .	Bowerbankia.
„ 3.	CYCLOSTOMATA . . .	Tubulipora.
„ 4.	LOPHOPHEA	Plumatella.
„ 5.	PEDICELLINIDA . . .	Pedicellina.

Class VIII.—Ascidioida.

Order 1.	BRANCHIALIA	Cynthia, ascidia.
„ 2.	ABDOMINALIA . . .	Clavellina, aplidium.
„ 3.	LARVALIA	Appendicularia.

SUB-KINGDOM CŒLENTERATA.

Class I.—Actinozoa.

Order 1.	CTENOPHORA	Cydippe, cestum.
„ 2.	CORALLIGENA	Alcyonium, pennatula, tubipora, *cyathophyllum*, actinia, madrepora, astræa.

Class II.—Hydrozoa.

Order 1.	HYDROPHORA . .	Hydra, coryne, tubularia, sertularia.
„ 2.	SIPHONOPHORA . .	Diphyes, physalia, velella.
„ 3.	DISCOPHORA . .	Rhizostoma, cyanœa, lucernaria, beroë.

SUB-KINGDOM PROTOZOA.

PROVINCE I.—STOMATODA.

Class I.—Infusoria.

Paramœcium, vorticella, noctiluca.

PROVINCE II.—ASTOMATA.

Class I.—Spongida.

Spongilla, halichondria, tethya.

Class II.—Radiolaria.

Thalassicolla, acanthometra, and other "Polycistina."

Class III.—Gregarinida.

Gregarina.

Class IV.—Rhizopoda.

Amœba, gromia, rotalia, *nummulites*, miliola, and other "Foraminifera."

VEGETABLE KINGDOM.*

Sub-Kingdom I. Phanerogamia (seeds containing an Embryo).

Class I. Dicotyledones (two cotyledons) **or Exogenæ** (outward growing).

SUB-CLASS I. ANGIOSPERMEÆ (seeds in a vessel).

GROUP I. THALAMIFLORÆ (petals distinct, stamens on torus).

Examples.—Buttercup, Berberry, Water-lily, Cabbage, Turnip, Chickweed, Poppy, Violet, Mallow, Lime, Tea, Orange, Maple, Mahogany, Vine, Geranium, Flax, Balsam, Rue.

GROUP II. CALYCIFLORÆ (petals distinct, stamens attached to calyx).

Examples.—Buckthorn, Cashew-nut, Pea and Bean, Acacia, Rose, Raspberry, Strawberry, Plum, Apple, Pear, Cherry, Almond, Peach, Mangrove, Myrtle, Cucumber, Passion-flower, House-leek, Cactus, Gooseberry, Currant, Saxifrage, Carrot, Parsley, Celery, Hemlock, Ivy.

GROUP III. COROLLIFLORÆ (petals united, bearing the stamens).

Examples.—Mistletoe, Honeysuckle, Elder, Cinchona or Jesuit's Bark, Coffee, Artichoke, Thistle, Chicory, Lettuce, Harebell, Heath, Rhododendron, Cranberry, Ebony, Holly, Jessamine, Olive, Ash, Gentian, Strychnos, Convolvulus, Belladonna, Tobacco, Potato, Henbane, Capsicum, Mullein,† Foxglove, Mint, Sage, Primrose.

GROUP IV. MONOCHLAMYDEÆ (corolla wanting, simple perianth).

Examples.—Spinage, Beet, Buckwheat, Rhubarb, Laurel, Cinnamon, Nutmeg, Banksia, Sandalwood, Pitcher-plant, Rafflesia, Aristolochia, Nettle, Fig, Mulberry, Breadfruit, Pepper, Willow, Casuarina, Birch, Plane, Hazelnut, Chestnut, Oak, Beech, Walnut.

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* The following sketch of the Vegetable Kingdom was communicated to me by my lamented friend Dr. W. H. Harvey, the year before he died, for publication in this edition of the Student's Manual.—J. B. J.

† This plant has an intense power of spreading over *new* lands—*e.g.*, in America, where it does *not* grow wild.

SUB-CLASS II. GYMNOSPERMEÆ (seeds naked).

Examples.—Fir, Spruce, Larch, Pine, Cypress, Juniper, Cedar, Yew, Cycas, Zamia, Welwitschia.*

Class II. Monocotyledones (one cotyledon) **or Endogenæ** (inward growing).

GROUP I. PETALOIDEÆ (usually a perianth).

Examples.—Yam, Orchis, Ginger, Arrow-root, Banana, Iris, Daffodil, Aloe, Pine-apple, Lily, Onion, Crocus, Rush, Palm, Pandanus or Screw-pine, Arum.

GROUP II. GLUMACEÆ (having a scaly sheath).

Examples.—Sedge, Reed, Papyrus, Grass, Corn, Sugar-cane, Bamboo.

Sub-Kingdom II. Cryptogamia (spores not containing an Embryo).

Class I. Acrogens (summit-growing).

SUB-CLASS I. FILICALES (Fern-sort).

Examples.—Fern, Adder's-tongue, Horsetail, Pepper-wort, Club-moss, "Nardoo" † (Marsilea).

SUB-CLASS II. MUSCALES (Moss-sort).

Examples.—Moss, Liverwort.

SUB-CLASS III. CHARACEALES (Chara-sort).

Example.—Chara.

Class II. Thallogens (no distinct axis). ‡

SUB-CLASS I. MYCETALES (Fungus-sort).

Examples.—Lichen, Fungus. §

SUB-CLASS II. ALGALES (seaweed-sort).

Examples.—Fucus, Laminaria, Conferva, Diatomaceæ.

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* Welwitschia is the most wonderful of all ligneous vegetables.—*Note by Dr. Harvey.*

† Eaten by blacks in Australia; Burke and Wills starved on it.

‡ That is the idea of the group, but it is not *confined* to it, nor *universal* in it. In Monocotyledones we have Semna (*duckweed*), a flower-bearing thallogen, and many of the Liverworts in Muscales are thallogenous.—*Note by Dr. Harvey.*

§ It is a moot-point whether *Lichen* and *Fungus* ought to be associated. Lichens are *never*, Fungi are *always* parasitic. (Tree-growing Lichens are only *epiphytes.*) Still, by many botanists, they are associated.—*Note by Dr. Harvey.*

III. MR. JUKES'S VIEWS ON DEVONIAN ROCKS.

SOME years before his death the author of this Manual, after much detailed examination of the geological structure of the south of Ireland, turned his attention to the rocks of Devonshire, to which the name of Devonian has been given. Struck with their general similarity of character to those known in Ireland as Carboniferous Slate, he proceeded to examine them more closely, and at length satisfied himself that the order of sequence in North Devon and in Ireland was the same, and hence that the so-called Devonian rocks were really the lower portion of the Carboniferous system, resting, as in Ireland, upon a base of Old Red Sandstone. These views were advanced first in some of the Explanations of the Sheets of the Geological Survey of Ireland, previous to the year 1865. In that year he communicated to the Royal Geological Society of Ireland some "Notes for a comparison between the rocks of the south-west of Ireland and those of North Devon, and of Rhenish Prussia, in the neighbourhood of Coblentz." Next year he read before the Geological Society of London a memoir in which his views were fully expanded, and in which he enters into considerable detailed argument to show that the Devonian rocks do not form an independent system, but are in truth the equivalents of the Carboniferous Slate of Ireland. In this paper the following passages occur :—"The hypothesis I offer for the interpretation of the North Devon section is based solely on the experience acquired by myself and my colleagues of the Geological Survey in the southern counties of Ireland. I believe that the County Cork, and the adjacent parts of Kerry, must be taken as the typical district for the classification of the Devonian rocks, and that the grouping of the rocks of the south of Ireland, resulting from the labours of Sir R. Griffith and Her Majesty's Geological Survey, must form the model for the grouping of the same beds in other countries.

"I do not, of course, mean to assert that the rock-groups of other countries must necessarily be the same as those of Ireland; but I certainly must maintain that, as the rocks of Ireland are clearly shown, and their order of succession can be observed in many localities, that order must be presumed to be the one which prevails in Devonshire, and in Western Europe generally, in all places *where no good reason can be shown to the contrary.*

"It happened that Devonshire was described before the south-west of Ireland, and described by masters in our science. Had those describers, however, been previously acquainted with the structure of the south-west of Ireland, they would have had reason to suspect that the apparent order of superposition in Devonshire was not the true one, and would doubtless have interpreted the sections in North Devon by the light of their previous Irish experience. Any one who has gained this experience, will, I believe, agree with me in the ideas I have formed respecting the structure of North Devon. I shall not, on the other hand, be at all surprised, if any one without this experience, who looks solely to North Devon itself, declines to accept them.

"My hypothesis is briefly this—that a great fault, with a downthrow to the north, strikes from the northern corner of Morte Bay, about east and by south, all across North Devon, somewhere near the villages of West Down, Bittadon, East Down, Challacombe, about a mile south of Simonsbath, and thence onwards in the same course."

The effect of this fault, in his opinion, has been to repeat on the north side a great series of beds, which have been generally regarded as middle Devonian, but which he believed to be of lower Carboniferous age, like those

to the south of the fault, which are usually termed upper Devonian. He maintained that the fossil evidence did not invalidate this supposition; that the difference between the fossils from different parts of the so-called Devonian rocks did not differ more markedly from each other than fossils from different parts of the Carboniferous Slate differed from each other; that the fossils of both groups of strata warranted the conclusion that they might have been geologically contemporaneous; that, on the supposition that the rocks of North Devon really formed a continuous ascending section to the base of the Carboniferous system, the total thickness of "Devonian" rocks seems so great as to require verification from some other district; that his explanation of a great fault not only removed the latter difficulty, but brought the rocks of Devon into harmony with the clearly-ascertained order of succession in the south of Ireland; and that, in this way, the term Devonian, instead of designating an independent geological system, should be regarded merely as a name for one type of the lower portion of the Carboniferous system. He concludes thus:—

"I would beg leave to suggest that the identification of the Old Red Sandstone proper with the Devonian beds was an over-hasty conclusion, and that, till the question be finally settled, it would be well to discontinue the use of the term Devonian for all beds which are, or are supposed to be, really Old Red Sandstone. One source of confusion would thus be avoided. The term "Devonian" would then be confined to beds containing those species and genera of Brachiopoda and other marine fossils which are commonly understood when we speak of Devonian fossils. The Old Red Sandstone certainly does not contain any of these fossils. The plants and the Anodonta which it does contain seem to point to a freshwater origin for it, or at all events the neighbourhood of land.

"The Devonian beds, when the Old Red Sandstone is detached from them, will still be sufficiently extensive and important. The peculiar genera and species belonging to them seem to have a very wide range over the world in general, quite as wide perhaps as the genera and species peculiar to the Carboniferous Limestone.

"I believe, however, that it will ultimately be found that the genera and species which have the widest range of all are those which are common to the Devonian beds and the Carboniferous Limestone.

"It may doubtless be thought a bold, not to say audacious, speculation, but it occurs to me to ask whether we ought not rather to look upon the Devonian beds as the most general type of those which intervene between the Coal-measures and the Old Red Sandstone, and regard the Carboniferous Limestone of the British Islands and Belgium as a local and exceptional peculiarity. It seems to me that good reasons might be urged for such a classification."

Mr. Jukes was removed from among us before he had time adequately to work out the views which he sketched as a reform in Palæozoic classification. He was a trained and most skilful adept in physical geology; and though his suggestion has not been adopted by the general body of geologists, there must still linger in many minds the conviction that a view which had recommended itself to so earnest and experienced a field-geologist is well worthy of serious consideration.*

* Mr. Jukes's views were opposed by Mr. Etheridge, who, in 1867, published an elaborate memoir on the "Physical Structure of West Somerset and North Devon, and on the Palæontological Value of the Devonian Fossils."—*Quart. Journ. Geol. Soc.* xxiii. 568.

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The names of fossils which are figured are printed in italics.

THE END.

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